Lawrence Radiation Laboratory

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RESIDUAL TRITIUM AT SEDAN CRATER
PART II. SOIL AND EJECTA STUDIES

John J. Koranda

John R. Martin

Robert Wikkerink

December 7, 1967

UNIVERSITY of CALIFORNIA
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FOREWORD

The first report on radioecological studies of residual tritium at the Sedan crater (UCRL-70292) was concerned with research conducted between January 1965 and February 1966. Although at the time UCRL-70292 was not formally considered as Part I of the radioecological studies, it has become the initial publication in a series of reports under the general heading: Residual Tritium at Sedan Crater. At various points in the text of this report (Part II) attention will be called to certain phases of the research program that will be reported in the near future, these reports to be published as parts of this series.

RESIDUAL TRITIUM AT SEDAN CRATER
PART II. SOIL AND EJECTA STUDIES

ABSTRACT

Continuing studies of residual tritium in soil or ejecta deposited on the landscape around the Sedan crater, Nevada Test Site, are concerned with the spatial and temporal distribution of THO in the area from the crater lip to 5000 ft from ground zero. Seasonal variations in the concen-- trations of tritium in soil water occur mainly during the winter rainfall period. Dilution effects were observed to a depth of 3 ft during an unusually high rainfall period (1965-1966). Diluted tritium con- centrations in the surface strata of soil (6 in. to 3 ft) increase to almost the pre- dilution levels during the summer as a result of soil moisture movements.

When Sedan ejecta occurs as a shallow layer overlying the preshot soil, maximum tritium concentrations are found in this soil, usually at the maximum depth of rainfall penetration, or approximately 3 ft. Maximum concentration of tritium in ejecta on the Sedan crater lip is found at a depth of 4 to 5 ft and is correlated with the depth of ejecta materials found around the crater lip.

An inventory of tritium in the Sedan ejecta field was calculated, based upon collections of soil samples along transects of the ejecta-covered area, and to a depth of 6 ft at each site. The tritium inventory measurements are essentially of biolog- ically available water in the soil system. When data are corrected to total soil- water tritium values, the current inventory of tritium outside the Sedan crater in 1967, five years postshot, is 5 to 6% of the estimated inventory of the residual tritium in the ejecta at shot time.

INTRODUCTION

The first report on radioecological studies of residual tritium at the Sedan crater[1] was concerned with research conducted between January 1965 and

February 1966. This research was of a preliminary nature, and specific approaches and techniques for the study of tritium in an open ecological system were developed. Full-time study began in August 1965 and, with increasing laboratory facilities, more detailed aspects of the study of residual tritium in the crater environment of the Sedan detonation have been investigated.

The purpose of this research is to determine the spatial and temporal distribution of residual tritium in the crater environment of a thermonuclear detonation, and to investigate the biological significance of the fraction of residual tritium which remains in the mass of earth moved by the detonation. The major concern is therefore with the biological systems which are associated with the postshot environment, and specifically, the interrelationships of those organisms with the substratum which contains tritium as THO. Our interest in the actual amounts of residual tritium created in a specific detonation lies only in the use of production values as basic input data with which a current inventory may be compared at a given point in time.

The range of subjects under field and laboratory study in the current program now includes ejecta soil, annual herbaceous and perennial woody plants, and two species of herbivorous animals. Insects, reptiles, birds, and carnivorous mammals are also present in the Sedan ecosystem and these biological subjects will be investigated in future work. The interest in these organisms is not based on their taxonomic or biogeographic status but on the fact that the organism may represent a certain trophic relationship in the ecosystem about which information is sought. Biochemical studies were also made of mammals living in the Sedan area and were reported by Hatch.[2]

METHODS

During the early part of 1966, specialized techniques and apparatus were developed which permitted the extraction of interstitial soil water, and tissue or body water from plants and animals. In this technique, nineteen samples per day are processed on a large vacuum manifold, each sample being extracted separately with the sublimed water being trapped in a large glass dewar which can condense over 300 ml of water. Several hundred grams of soil or 70 to 200 g of fresh green plant material are processed, usually in duplicate, to obtain a single analysis. In all of the tritium concentrations reported here, 200 to 500 g of soil were extracted and 50 to 200 g of plant tissues were lyophilized. The entire carcass of the small mammal is lyophilized to obtain its body water. Extraction times are usually 24 hr or longer. The analytical techniques and apparatus used in these studies will be described in a future report.

The large amounts of sample processed in this system impose a greater work load on the analyst, but it is believed that the larger sample (1) provides a greater degree of confidence in the determination, eliminating the variability inherent in small samples, and (2) permits the use of the lyophilized sample residue for other analyses. Since the overall program is concerned with all radioisotopes produced in an event, the lyophilized samples are also assayed for gamma-emitting radio-isotopes and these larger samples are necessary to obtain sufficient activity for gamma spectroscopy.

In connection with the soil-water tritium concentrations reported here, it should be noted that the vacuum extraction of interstitial soil obtains all capillary and most of the hygroscopic water present in the soil system as free water. This extraction is apparently equivalent to oven-drying at 110°C for 24 hr. However, tritium may still be extracted from the lyophilized soil sample by elution with "dead" or stable water using exchange periods as short as 4 hr. Thus the tritium remaining in the extracted soil sample is readily exchanged and could enter into the available soil-water (capillary and hygro-scopic) compartment, and affect the variation in concentrations evident in these data. The nature of the physical states in which tritium occurs in earth moved by nuclear detonations is presently under study and will be the subject of a future report.

The tritium determinations cited in this report were made by liquid-scintillation counting methods utilizing a Packard Tri-

Carb Model 3375 spectrometer. Computer reduction of liquid-scintillation data with appropriate standards and background samples is accomplished by a special free-format program.[*] All samples are counted in duplicate, and the error of measurement is usually less than 3%. Tritium concentrations in this report are expressed in disintegrations per minute per milliliter of water (dpm/ml).

The sampling of soils is done in the following manner. Soil samples are obtained with a conventional posthole auger which has been modified slightly by adding a 4-ft length of galvanized pipe to the handle. With this auger samples are obtained to a depth of 6 ft. The uncertainty in obtaining a soil sample from a discrete depth level with this type of auger is ± 3 in. Soil samples are sieved in the field with a sieve that passes all particles less than 2 mm in diameter. Comparison of sieved and unsieved sample data shows no measurable effect of the sieving upon the THO concentrations in soil water. The purpose of the sieving is to remove from the soil sample the stones and gravel which influence a soil moisture determina-tion and are not extremely important in the retention of interstitial soil water. Soil samples are sieved directly into large-mouthed Mason jars, and the rubber-gasketed lids are taped with pressure-sensitive tape.

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[*]This free-format program was de-veloped by Bruce Clegg and John R. Martin of the Lawrence Radiation Laboratory. The details of the program and the count-ing procedures will be described in a future report.

PREVIOUS RESULTS

The results of the first period of study at the Sedan crater[1] indicated that residual tritium as THO was found at microcurie levels in soil water, with a steep profile of increasing radioactivity with depth. Seasonal rainwater apparently dilutes the soil-water tritium levels in the first 3 ft of soil. Plants take up THO in soil water, and microcurie levels per milliliter of tissue water were found in all plant species as far as 2000 ft from the crater lip. The presence of tritium in evapotranspirational water released by the foliar surfaces of the plant species growing on the Sedan throwout apparently increases the tritium level in surface air around the Sedan crater.

Tritium concentrations in the microcurie per milliliter range were found in small mammals living on the Sedan throwout area. These tritium concentrations in the body water of small mammals were apparently due to the ingestion by the animals of plant food which contained a high level of tissue-bound tritium. The main food of these animals is seeds. Analyses of tissue-bound tritium in plants indicated that tritium concentrations in the water of combustion of plants growing at the Sedan crater approximated those found in the soil water, and in the loose or constituent water of the green plant tissues themselves.

With these basic facts elucidated in the preliminary phase of these studies, further research was directed toward certain key aspects of the Sedan ecosystem where tritium was known to be present in high concentration, especially in biological subjects. The following are some areas of inquiry about which information was sought:

1. Soil physics. What is the physical nature of residual tritium in ejecta from a nuclear detonation? Is tritium present only as adsorbed THO scavenged by earth materials as they fall back to earth through the cloud or are there mineral-bound phases of tritium in the ejecta? Does adsorbed THO exchange with any mineral-bound phases of soil water or hydrogen? Does residual tritium in soil respond to simple elution kinetics? Can it be "washed" from throwout earth materials by rainwater? Is there any evidence of a dilution or depletion of tritium in the Sedan ecosystem as the result of environmental or biological factors? What is the present distribution of tritium in the Sedan ejecta field? What is the present inventory of tritium at the Sedan crater?

2. Plant physiology. What is the effect of plant uptake of soil water upon the specific activity of THO in the various compartments of this physio-biological system? Are there any fractionation effects as tritium moves from the soil through root and shoot membranes, finally being transpired (evaporated) at the leaf surface? Does tritium occur at the same specific activity in organic matter synthesized in the Sedan ecosystem as it does in the tissue water of plants and in the soil water? Will deep-rooted woody plants have a different pattern of

tritium fixation due to more complex hydrogen compartments in the form of wood, and due to continuous exposure because of their perennial nature?

3. Animal physiology. What is the significance of mammal-body-water tritium concentrations at the Sedan crater? Were the body-water concentrations observed in 1965 and early 1966 a single occurrence or does the entire resident population of small mammals at the Sedan crater exhibit body-water concentrations of tritium in the same range? Will the body-water tritium burdens observed in 1965 be found in progeny of the resident animals? Will recently emigrated species acquire tritium burdens via the same physiological route, their food base, as they enter the Sedan environment? Does an animal subjected to chronic tritium exposure receive a significant additional dose from tissue-bound tritium sources?

These are some of the questions that were asked by the investigators as they entered the advanced phases of this research. Some of the answers to these questions, and others that occurred enroute, are in this report. Others will be found in subsequent reports describing aspects of this work considered discrete enough to warrant separation from the main body of information.

SOIL STUDIES OF SEDAN EJECTA

The soil-water tritium concentrations reported in Ref. 1 indicated an increase in concentration with depth to at least 3 ft at most of the sample sites. This depth does not represent the maximum depth from which plants obtain water, and therefore if higher concentrations existed in deeper strata they would have some biological significance. Also it is possible that THO in deeper strata may be brought to the surface strata by soil-water movements and replenish the concentrations occurring in the surface zone as losses occur by evaporation. Annual herbaceous plants may obtain water from much deeper levels than 3 ft, and woody plants with deep roots can obtain water from depths approaching 100 ft (Ref. 3). A conventional soil auger was adapted to obtain soil samples as deep as 6 ft.

1966 SOIL-WATER TRITIUM DATA

In March 1966, sample holes were dug on the crater lip to determine the depth profile of soil-water tritium in four different areas. A depth of 5 ft was reached in one of these holes while 4 ft was the maximum depth in the other three holes. The depth of fallback or ejecta on the crater lip, according to Richards,[4] is 1 to 4 ft, with the average depth around most of the crater between 3 and 4 ft. Apparently most of the samples were entirely in ejecta, although at 11A, station

on the crater lip, it is possible that the sample taken at a depth of 5 ft was in overturned alluvium. However, the tritium concentration from the sample at the 5-ft depth at the 11A station was approximately the same as that occurring in the sample at the 4-ft depth. If the sample from the 5-ft depth is in the overturned alluvium materials, then either comparable tritium levels occur in the alluvium below the ejecta layer, or THO from the ejecta layer has diffused into the alluvium below. Since most of these sample holes extended only to the depth where contact with the overturned alluvium might be expected, it is not possible to determine from these data whether the sample hole transected the entire ejecta layer. Tritium concentrations in soil water have been found below the ejecta layer but because mass movement of water in these desert soils usually does not occur below 3 ft — and rarely at 4 ft — some other transport mechanism must be responsible.

Data for the 9A sampling station were obtained at 600 ft from the crater lip. The crater lip is highest in the 9A area due to certain events that took place during the cratering and venting process when the surface mantle of earth was being lifted somewhat asymmetrically by the explosive force of the detonation. Tritium concentrations in the throwout of this high point are lower than at other sites around the crater lip.* The elevation of the Sedan crater lip at various points on its circumference is shown in Fig. 1.** The locations of the sampling stations

and crater lip positions of transects used in these studies are shown in this figure.

Soil-water tritium concentrations in March 1966 are shown in Fig. 2, and were obtained from samples deeper than those collected in any of the preliminary studies. In the single hole in which it was possible to reach a depth of 5 ft, maximum tritium concentrations occur at 4 ft at the 11A sampling station on the south edge of the crater lip. From the data in Fig. 2, it is apparent that the concentrations of tritium found in four different holes at four widely separated points on the crater lip are all within an order of magnitude of each other at a given depth.

The average concentration of tritium in a composite sample of fallback within the crater itself, representing the depth interval from the surface to 25 ft, was 0.33 μCi/g of soil with adsorbed water at 4.6%.[6] This value is 7.16 μCi/ml of soil water, which is within the range of tritium concentration currently found at the 4- to 5-ft depth on the crater lip (2.2 to 9.5 μCi/ml). At 187 ft in the crater fallback, the maximum tritium concentration was found by Knox[6] to be 0.47 μCi/g at 6.5% adsorbed water. This value is equivalent to 7.24 μCi/ml.

Thus the maximum fallback and crater-lip-ejecta tritium concentrations are in the same range, confirming our assumption that this would be the case. The values cited above agree well with each other, and this agreement indicates that these data, produced independently, may be regarded with a high level of confidence. Also, we might conclude that the tritium scavenging efficiency of fallback and close-in ejecta was quite similar. The single sample hole in which a depth of

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*See Fig. 13.
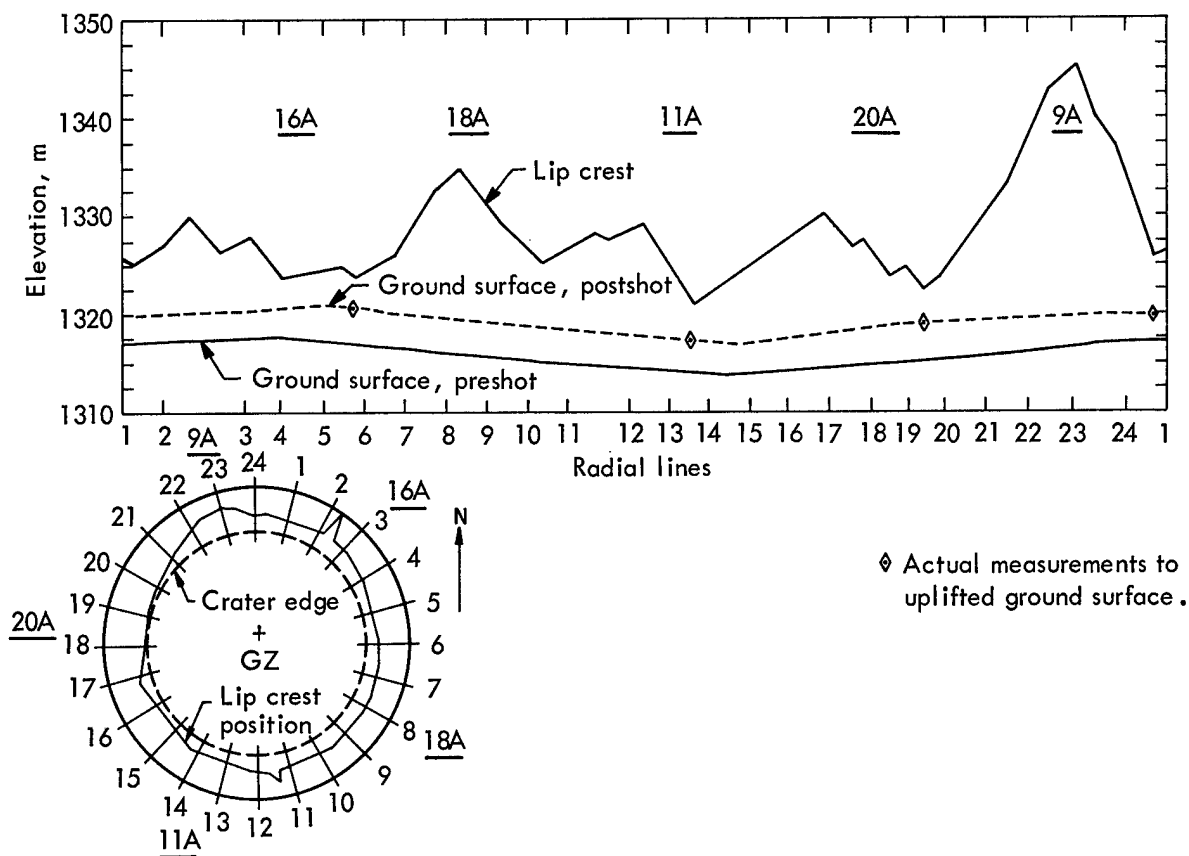**Taken from Carlson and Roberts.[5]

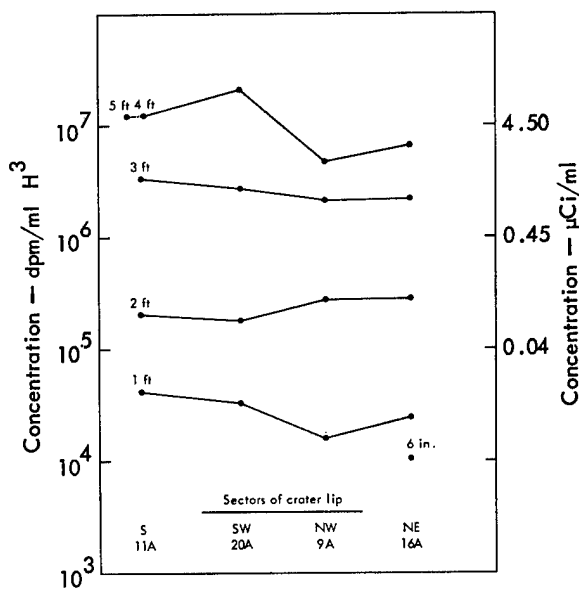Fig. 1. Station designations for sectors of Sedan crater lip.

Fig. 2. Soil-water tritium concentrations for samples from various stations on Sedan crater lip (March 1966).

5 ft was reached produced data that indicated no further increase in tritium concentrations below 4 ft. Since 4 ft was the maximum depth of fallback or ejecta measured by Richards[4] in trenches which transected the crater lip, we will consider this depth as the maximum thickness of ejecta expected in sampling this layer.

The data given in Ref. 1 for tritium concentrations at 2000 and 4000 ft from ground zero (GZ) indicated a steep slope of decreasing concentration with distance. This slope of concentrations, determined in 1965-1966, approximately 3-1/2 years postshot, is undoubtedly due in part to dilution effects from rainwater which would influence a thin layer of ejecta (beyond 2000 ft from GZ) more than the

thick layer at the crater lip. It is quite possible, however, that all of the kilograms of ejecta deposited on the landscape around the crater, some on long trajectories of 2000 to 4000 ft, did not have the same amount of tritium accompanying them. Longer transport might well also imply greater losses which would produce a slope of concentration with distance from the source, especially if the THO were merely surface-loaded on the earth materials.

Because early analyses of tritium in the ejecta field were not made, it is not possible at this time to determine the actual losses in tritium inventory in ejecta at points distant from the crater. Evaporation, evapotranspiration, and other environmental processes have dissipated in part those initial levels in an indeterminable way, and dilution by rainwater has taken place in what remains. However, current inventories at points distant from the crater will be given in $\mu Ci/m^2$ later in this report.

In discussing depositional variations in tritium concentrations, we must not overlook the possibility that vertical differences in the ejecta layer are responsible for the steep gradient of tritium concentration with depth that is apparent in these data. Carlson and Roberts[5] describe two observable layers in the ejecta at points 427 to 640 m from GZ. The lower layer, called the bulk ejecta layer, was deposited in mass and probably incurred small losses of volatile detonation products, while the upper layer (missile-ejecta layer) is composed of fine base surge materials, debris on high trajectories, and fused silicate materials. The bulk ejecta layer therefore might be expected

to have tritium concentrations similar to the crater lip and crater fallback, while the missile-ejecta layer would be a zone of tritium depletion varying in its degree of depletion with distance. A slope of tritium concentrations decreasing with distance from the crater and increasing with ejecta depth is quite possible therefore on a depositional basis.

In May 1966, soil samples were obtained from holes dug in the same areas in which the March samples were obtained. Samples from the 5-ft depth were obtained from three holes, and a sample from the 6-ft depth was taken from the 11A station.

The collection of samples from depths of 5 and 6 ft is limited by the occurrence of large rocks in the direct line of the sample hole. It is nearly impossible to remove a large rock from a 1-ft diam hole at a depth of 4 to 5 ft, and therefore the profile is terminated at that point. Soil-water tritium data from sampling the crater lip in May 1966 are shown in Fig. 3, and in Fig. 4 are compared with the March data. In the May 1966 sample data shown in Fig. 3, tritium concentrations continue to increase beyond 4-ft depths at two of the stations, and reach maximum concentrations at the 4-ft depth at the other two stations. At the 11A station, the further decrease at the 6-ft depth indicates that the maximum concentrations are actually at 4 ft, in agreement with the March data. In Fig. 4 it can be seen that most of the variation in tritium concentrations that has taken place at these four stations is in the shallow strata, while the values at 4 ft are relatively constant. Some significant lowering of the tritium concentration at all
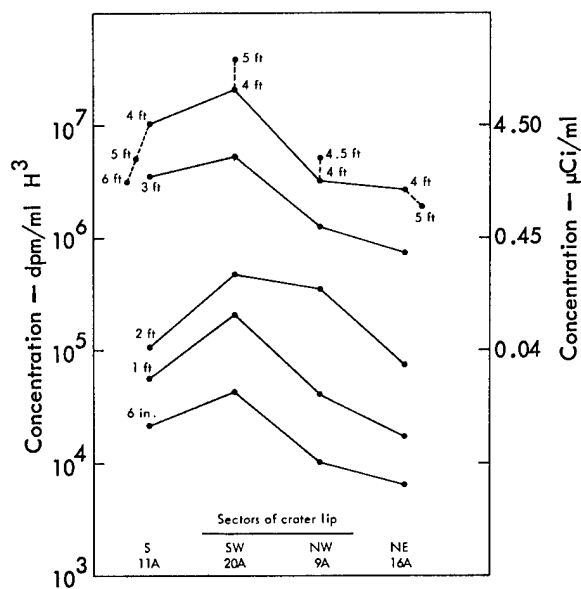
Fig. 3. Soil-water tritium concentrations for samples from various stations on Sedan crater lip (May 1966).
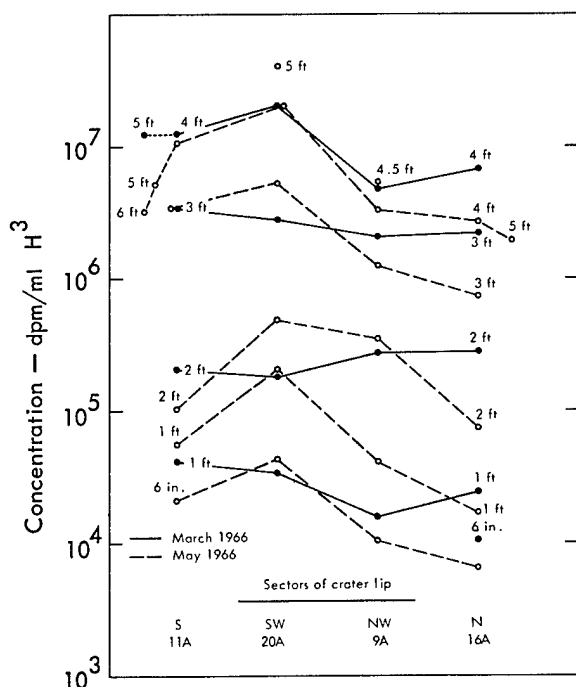

Fig. 4. Soil-water tritium concentrations for samples from various stations on crater lip (March 1966) compared with those in May 1966.

depths seems to have taken place in the profile for the 16A sampling station.

Two sample series (March and May) taken over such a short period of time indicate only the current levels of tritium. These levels may be influenced by winter rainfall dilution or by other soil-water dynamics, such as upward diffusion and evaporation of soil water at the soil-air interface during the summer. A continuous soil-water tritium concentration record for a single station yields the most information on the status of current levels of tritium, and such data will be presented later in this report. The value of these individual sample series is therefore in the long-term relationship of radio-activity data to various environmental parameters, such as amounts and distribution of rainfall and soil moisture regimes.

During the spring and summer growing season, the levels of soil-water tritium must be known in order to correlate concentrations found in plant tissue water, and those being released by evapotranspiration. Therefore, soil-water tritium data provide general information on the levels of tritium in the Sedan ecosystem at a given time, and specific data on the spatial and temporal distribution of tritium at sites which are repeatedly sampled.

In May 1966, a series of samples from the crater lip to 4000 ft from GZ were obtained on the 20A transect (southwest of GZ) and on the 16A transect (north-northeast of GZ). Considerable difficulty is experienced in obtaining discrete soil samples from depths such as 3 ft in un-disturbed soils, as are found at 4000 ft from GZ. The presence of rocks and

compacted soil hinders precise soil sampling in these undisturbed sites. Figures 5 and 6 contain the transect data obtained in May 1966.

The data in Figs. 5 and 6 indicate that, at 2000 ft from GZ or 1400 ft from the crater lip, peak tritium concentrations do not occur in the ejecta layer. Maximum concentrations of tritium in soil water are found at depths between 2 and 3 ft at 2000 ft on both transects, while the depth of ejecta at that distance from the crater was only between 16 and 18 in.

It is also of interest that at 4000 ft from GZ, where presumably only a very shallow layer of base surge materials was deposited, there is an elevated soil-water tritium concentration which increases with depth. At this time background soil-water tritium levels at the Nevada Test Site (NTS) were less than 10 dpm/ml, below detection by liquid-scintillation counting. Tritium assay was performed by Isotopes Inc., Westwood, N.J. by the more sensitive technique of internal fill gas proportional counting. Soil water at 2 ft on the 16A transect 4000 ft from GZ was approximately 380 dpm/ml (5.29 $\times 10^4$ T.U.) while environmental water at Mercury (Nevada) was 500 T.U. on the same date. Therefore, at 4000 ft from GZ, soil-water tritium concentrations were two orders of magnitude above local fallout tritium levels, where no obvious amount of ejecta was present at the time.

Soil sampling was continued during the summer of 1966 in August and September
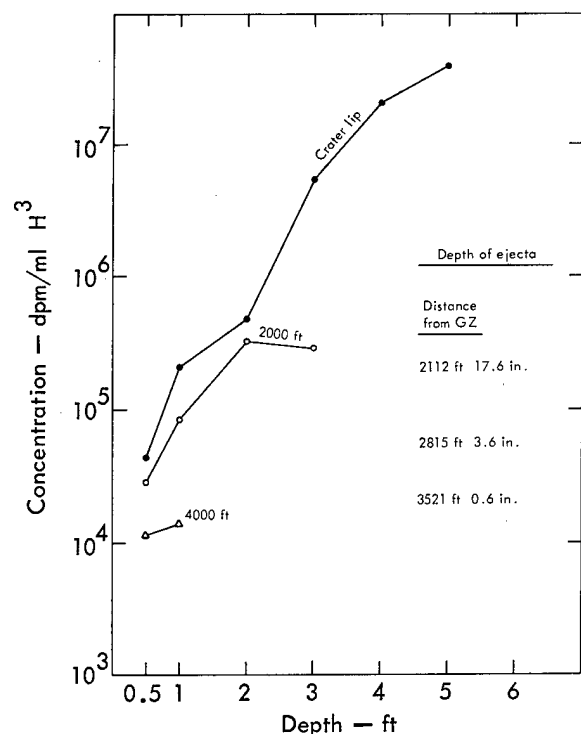

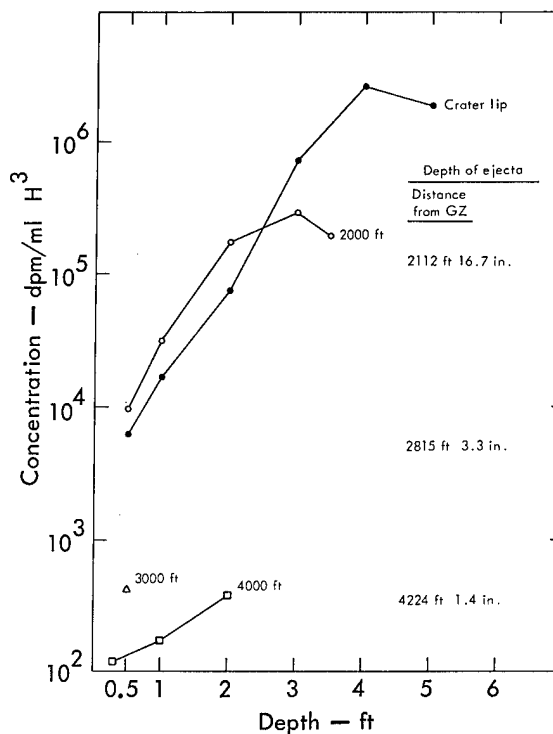Fig. 5. Soil-water tritium concentrations for samples from 20A transect (May 1966).

Fig. 6. Soil-water tritium concentrations for samples from 16A transect (May 1966).

to provide basic radioecological data on the Sedan ecosystem, and to further investigations concerned with the distribution of residual tritium throughout the ejecta field.

In Fig. 7, soil-water tritium concentrations are shown for five sample holes on the Sedan crater lip which were dug in August 1966. All sample holes were dug to a depth of 5 ft. The hole at the 9A station was dug on the highest point of the crater lip at an azimuth of approximately 345 deg. The uniqueness of the 9A area tritium concentrations is obvious in these data, and the concentrations at the 4-ft depth at the 9A station are three orders of magnitude lower than at 4 ft at other crater lip sites e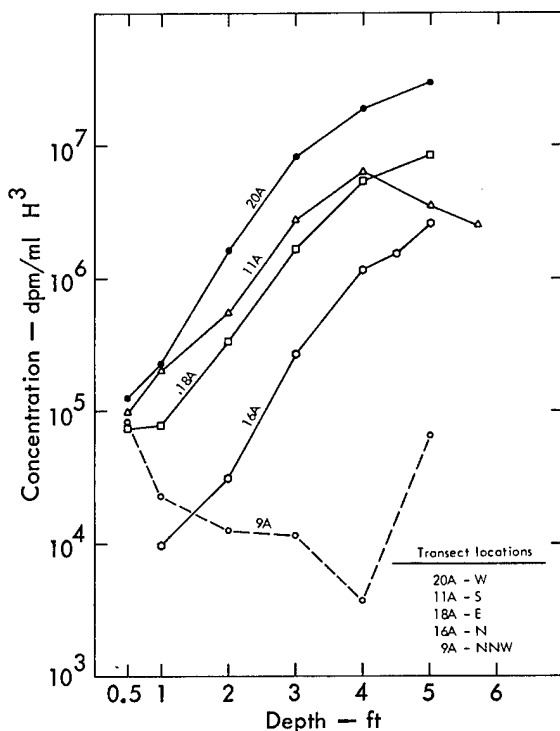xcept 16A. Richards[4] found little or no fallback on the high slumped area at the 9A station. Whatever the materials are on the 9A prominence, they were apparently exposed to and retained tritium during the cratering process because the concentrations found there are considerably above background. The steep increase at the 5-ft depth might indicate that this mass of earth remained relatively intact during the detonation and its movement, and that the inner surface (now buried) was exposed to more gaseous detonation products than the outer surface. Data are insufficient to explain satisfactorily the tritium increase at the 9A station at a depth of 5 ft.

Three soil profiles show tritium concentrations that are still increasing at 5 ft, while at the 11A station concentrations reach a maximum at 4 ft, repeating the profile obtained in May. It is apparent that at 6 in., all profiles, except that for the 16A station have very similar concentrations. It is possible that microclimatic and microtopographic factors affect tritium concentrations in soil water at shallow depths.

The August 1966 crater lip data indicate that it is possible that in three crater ejecta sectors depths may be on the order of 5 ft. The continued increase of tritium concentrations at the 5-ft depth, which is below the theoretical maximum depth of ejecta, would seem to indicate that the entire soil profile was composed of ejecta. On the other hand, the tritium occurring at 5-ft depths could have been leached there because mass flow from above pushes ahead of it a front of almost undiluted water. This phenomenon has been demonstrated in the laboratory. But there is little evidence of soil-water tritium dilution at 5 ft, so that mass flow

Fig. 7. Soil-water tritium concentrations for samples from five holes on crater lip (August 1966).

at those depths is unlikely. Vapor trans-
fer and condensation may account for some
movement of soil water under the condi-
tions being discussed. The point at which
tritium concentrations begin to decrease
may be a good index of ejecta depth, and
when a more complete soil profile is ob-
tained the value of this index may be
confirmed.

The low tritium concentrations found
on the high slump area at the 9A station
certainly substantiate the measurements
of Richards[4] which indicated reduced
amounts of fallback in that area.

The differences between data from the
20A sampling station and data from the
other sampling stations are real and not
sampling variations. With such a steep
gradient associated with depth, it might
appear possible to produce a large un-
certainity in data from sampling variation.
For example, we might obtain material
from the walls of the sample hole rather
than from the bottom. To measure the
uncertainty, two sample holes were dug
within 5 ft of each other at the 11A station
on 25 August 1966. The data from both
holes are shown in Fig. 8. Between 6
and 18 in., the variation between the two
holes amounts to the difference in con-
centration related to 3 to 6 in. of depth.
From 2 to 4 ft, the data are essentially
identical, and at 5 ft, the difference in
concentration is that produced by a depth
of 6 in. The average uncertainty is ±3 in.
In August the profile data for the 11A
station at 4 to 5 ft were the same as they
were in May 1966, with the maximum
occurring at 4 ft.

In August 1966, a series of soil profile
holes were dug on the 20A and 16A tran-
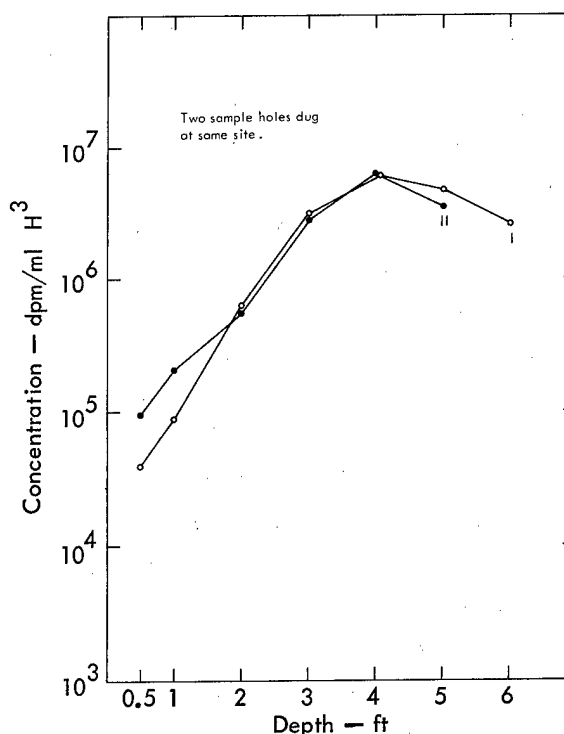sect lines to a distance of 4000 ft from GZ

Fig. 8. Comparison of soil-water tritium
concentrations for samples from
11A station on crater lip (August
1966).

on the 20A transect, and to 5000 ft from
GZ on the 16A. The transect was extended
1000 ft farther on the 16A because this
direction was almost on the "hot line,"
or the direction of travel that the cloud
took after the detonation. The soil-water
tritium concentrations determined in
those sample holes are shown in Figs. 9
and 10. The data indicate that (1) the
same relationships seen in the March 1966
data exist; namely, crater lip profiles
which did not reach maxima at 5 ft, at
2000 ft from GZ maxima are found in the
parent soil materials which were covered
by ejecta; and, also, that (2) at 4000 ft on
the 20A transect and 5000 ft on the 16A
transect, elevated levels of tritium are
found at a depth of 2 ft in undisturbed soil.
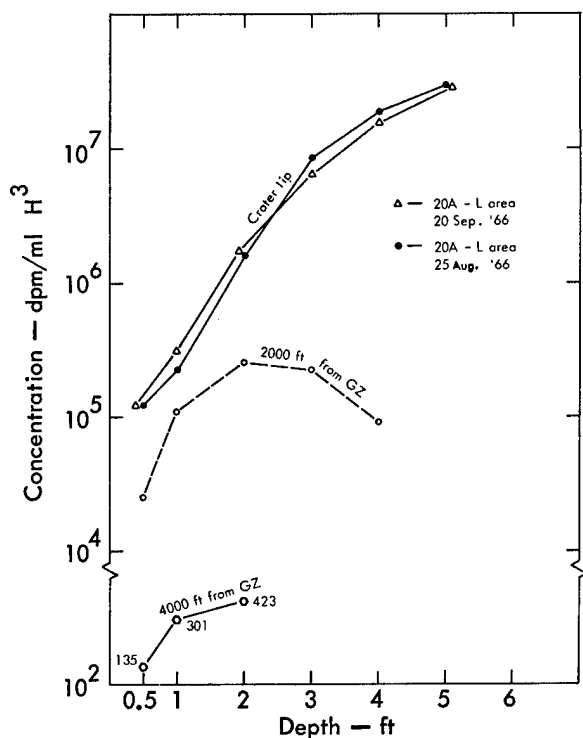In Fig. 9, data from two sample holes

Fig. 9. Soil-water tritium concentrations for samples from 20A transect (August and September 1966).
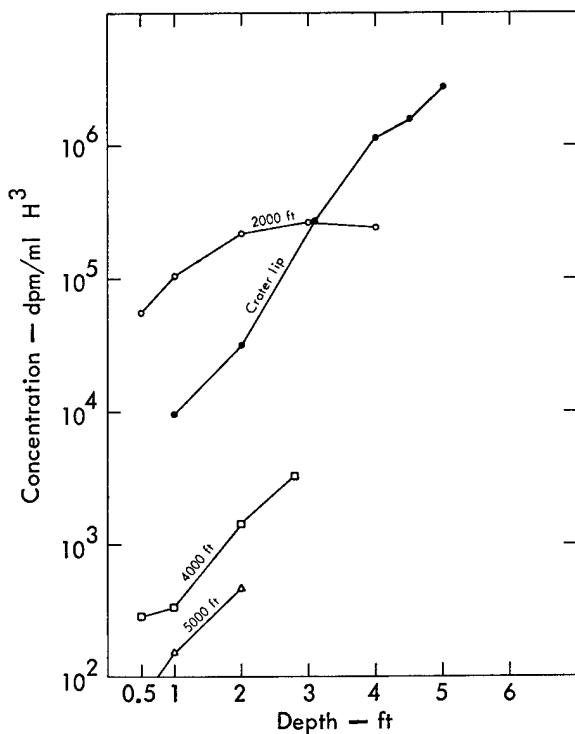
dug almost a month apart are compared, and these holes are essentially identical in their concentration profiles. By late summer, the THO concentrations in the soil profile are essentially stable. Summer rainfall sometimes affects the concentrations in the 0 to 12-in. stratum, but is is usually not very effective in diluting soil-water THO concentrations because of the rapid evaporation that takes place at this time.

The same agreement was also seen in data (Fig. 11) from the 11A station where sample holes were dug on 25 August and 22 September 1966. During this sampling trip two holes were dug at 1000 ft from GZ at the 18A station (south-southeast side of crater) and at the 11A station. Data are shown in Fig. 11. Sample data

Fig. 10. Soil-water tritium concentrations for samples from 16A transect (August 1966).
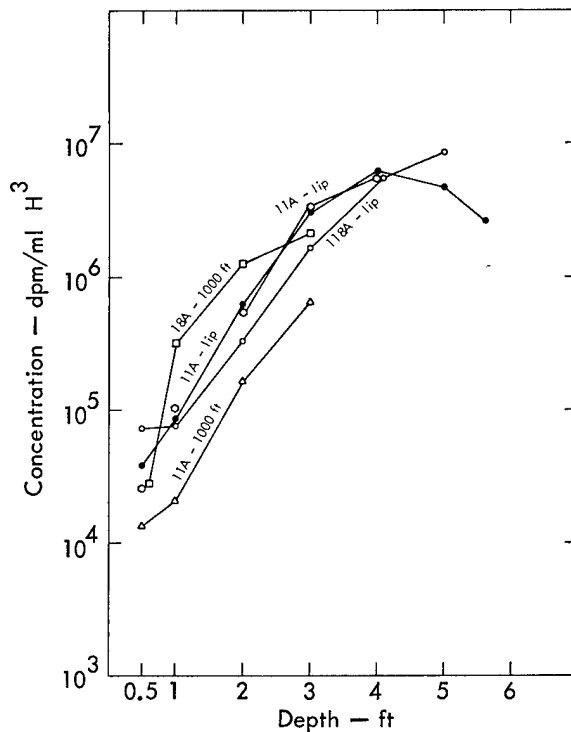

Fig. 11. Soil-water tritium concentrations for samples from 11A and 18A transects (September 1966).

from the holes 1000 ft from GZ indicate a similar concentration profile with increasing radioactivity at greater depth. In the case of the 18A station, significantly higher concentrations than those of the lip area were found at 1- and 2-ft depths.

In summary, the soil-water tritium data obtained in 1966 indicate that crater lip concentrations are (1) relatively uniform from station to station except for a high mound area on the north-northwest edge of the crater, and (2) at the maximum depth sampled are approximately the same concentrations found in fallback in the crater. A steep profile of THO concentration with depth is present in the ejecta at least to 1000 ft from GZ, and, at 2000 ft from GZ, peak THO concentrations are found in the original soil materials which were covered by a shallow layer of ejecta. Tritium, as THO, constituting the most soluble and mobile of the radionuclides in the ejecta, has been easily translocated or leached into the undisturbed preshot soil profile by the modest amount of rainfall (3 in.) received in this desert region. The depth at which maximum tritium concentrations occur shows good agreement with the expected maximum depth of ejecta on the crater lip. If ejecta is the main tritium-scavenging material moved by the detonation, then maximum tritium concentrations are not likely to be found below the ejecta on the crater lip because this depth is below the effect of most rainfall at this site. Rainfall elution would be the most significant process by which tritium is translocated.

Soil-water tritium concentrations in the 1- to 3-ft stratum are affected by seasonal increments of rainfall, and variations occur in that zone. The variations in the soil-water tritium profile for the 20A crater lip station are summarized in Fig. 12 for the period December 1965 to September 1966. In November and December 1965, 4.8 in. of rainfall were recorded at the USWBS BJY station, just south of Sedan crater. In January 1966, an additional 1.6 in. fell, and THO concentrations began to drop at the 3-ft depth. No significant rainfall fell after January in 1966 until July when 0.94 in. was recorded, but this period is the time of maximum evaporation and evidently there was no effect on soil-water tritium concentrations at this station. Following the unusually high winter rainfall in 1965-1966, minimum tritium concentrations occurred at 1 ft in February, and at 2 ft and 3 ft in March. It is interesting that the THO concentration at 4 ft dropped in August and September 1966; this drop may be related to the replacement of tritium in the shallower strata (1 to 3 ft) after the dilution that took place in January and February 1966. It is obvious that soil-water tritium concentrations are affected by soil-water dynamics, which are a function of the physical characteristics of the soil mass, the intensity and distribution of rainfall, and other environmental factors such as insolation, wind, and microtopography.

The value of periodic soil sampling is seen therefore in the soil-water THO regime shown in Fig. 12. It appears from this brief record of soil-water dynamics at a single station of the Sedan crater lip, obtained during a period of unusually high rainfall for the region, that there is a recharging of the shallower soil strata (1 ft to 3 ft) with THO from deeper sources
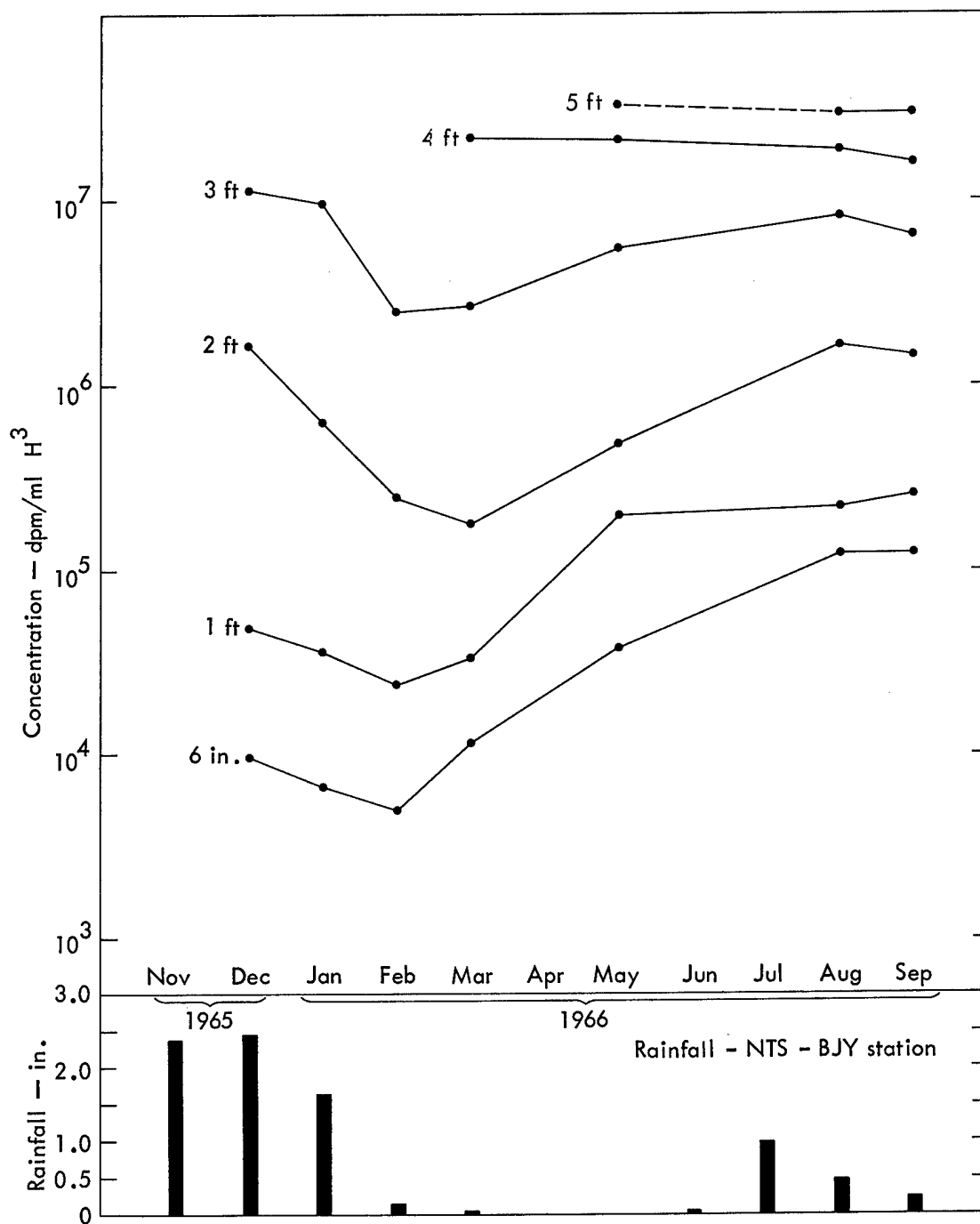
Fig. 12. Soil-water tritium concentrations for samples from 20A station on crater lip (1965 to 1966), showing rainfall.

which are known to exist (10^7 dpm/ml at 5 ft). The gain in dpm/ml in the shallow strata amounts to 7.4×10^6, while the apparent loss at 4 ft is only 5.0×10^6. These data evidently do not record the entire system, and it is quite possible that a continuous record of deeper strata (below 4 ft) would provide a more complete inventory.

It is obvious that whatever amount of residual tritium is created in a thermo-nuclear detonation and retained in the fall-back and ejecta, residual tritium is one of

the most mobile radionuclides in the bio-
logical and physical systems that evolve in
the postshot environment. The relation-
ship between tritium and other radio-
nuclides, especially gamma-emitters, is
described in other parts of this report to
demonstrate this mobility (which is not
unexpected for a substance such as water).

1967 SOIL-WATER TRITIUM DATA

Winter and Spring 1967 Data

In January 1967, six crater lip
stations were sampled to a depth of 5 ft,
and to a depth of 6 ft in the case of the
11A station. Two additional sample holes
were dug, one at 400 ft from the crater
lip on the 18A transect and one at 250 ft
from the crater lip on the 9A transect
(the base of the elevated portion of the lip
at 9A). The soil-water tritium concen-
trations in the samples collected in
January 1967 are shown in Fig. 13.

It is apparent that tritium concen-
trations reach maximum levels at all
stations either at 4 or 5 ft, which is ap-
parently correlated with maximum ejecta
depth. At the 11A, 16A, and 18A stations,
data indicate decreasing concentrations
after the 4- or 5-ft maximum, while at the
20A and 12A stations concentrations do
not decrease after the 4-ft depth. In the
1966 soil sample series, the profile for
the 20A station showed tritium concentra-
tions which continued to increase at 5 ft
(Figs. 7 and 9) to a concentration of
3.0×10^7 dpm/ml. The decrease at the
5-ft depth (20A station) may be related to
the gain in radioactivity seen in the
shallower strata late in 1966. Subsequent
sampling in 1967 may explain this apparent
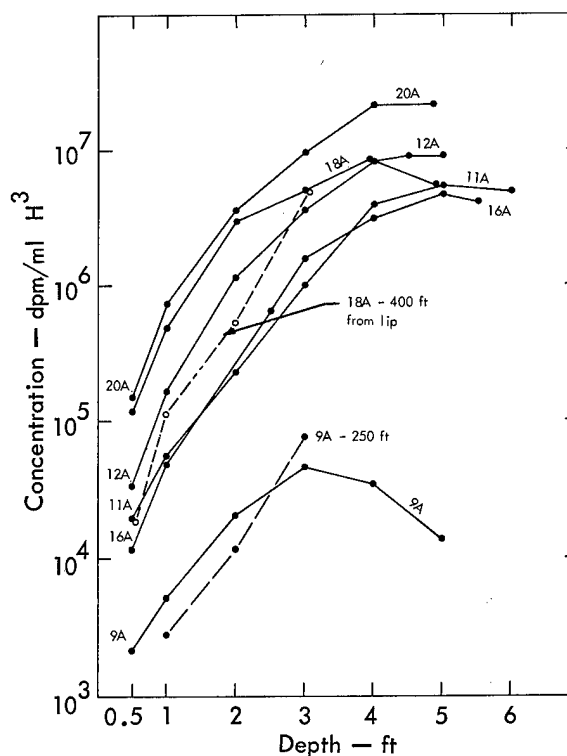decrease in tritium concentrations at a

Fig. 13. Soil-water tritium concentrations
for samples from six crater lip
stations (January 1967).

depth of 5 ft. An effect of this type may
not take place during years of normal
rainfall.

The tritium concentrations at the 9A
station are one to two orders of magnitude
lower than those from other sectors of the
crater lip. At station 9A on the crater
lip, tritium concentrations decrease below
3 ft, similar to the concentration profiles
at 2000 ft from GZ, where only a shallow
deposit of ejecta is present. The data
from the 9A station, 250 ft from the crater
lip (although the hole did not extend deeper
than 3 ft), indicate a different profile of
tritium with depth, similar to other crater
lip stations. Earlier sample holes dug
along the 9A transect 200 to 300 ft from
the crater lip also indicated that ejecta
along this transect was typical of crater
lip sites when the sample hole was placed

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away from the elevated mound at Station
9A (Figs. 2 and 3). Lower concentrations
of tritium have been found in plants and
animals in the 9A-crater lip area and the
lower soil-water tritium concentrations
are obviously the reason for those lower
biological levels.

From the January 1967 tritium data
for five soil sample holes dug at various
points on the crater lip, it is apparent
that, if the data for the 9A station are ex-
cluded, the variation in the tritium concen-
tration for the 6-in. to 2-ft zone is greater
than at the 5-ft depth where four stations
show concentrations between 4.0 and
9.0×10^6 dpm/ml. This is to be expected
because the surface soil horizons are
those most affected by incoming soil water
as rain. Also soil surface evaporation
and plant evapotranspiration will exert
their strongest effect on this soil stratum.
This zone is essentially the ecologically
active zone which, however, is not
isolated from the soil materials at greater
depths as it will be shown. The actual
level of dilution and reduction in the con-
centrations of tritium in this zone can be
seen in these data. If we assume that
the 5- to 6-ft concentrations represent the
concentrations of tritium present just after
the detonation (affected only by radiological
decay), then the total effect of all environ-
mental processes in dissipating residual
tritium after the detonation is represented
in the decrease observed from the soil
surface to 4 ft. This conclusion would be
reasonable only if those tritium concentra-
tions observed in Fig. 13 and elsewhere
in this report were static. But a natural
ecosystem is dynamic, and no environ-
mental parameter varies without exerting
one or more concommitant effects on the

system, effects which may be either
physical or biological, or both.

To illustrate this point, the soil
moisture data for samples collected at
the 20A station (west side of crater) have
been compiled for the period December
1965 to January 1967, and are shown in
Fig. 14. Rainfall data are also given on
the abscissa in inches of rain received at
the USWBS BJY station, just south of the
Sedan crater. In October and November
1965, 2.48 in. of rain fell, and, with the
1.6 in. received in January 1966, the
winter rainfall amounted to over 4 in. By
December 1965 the 6-in. to 2-ft stratum
was already close to the field capacity for
the soil. With evaporation at a minimum
during the winter, this unusual amount of
rain soon penetrated to a depth of 3 ft, as
shown by the rise from 6.2 to 10.4% for
the 3-ft depth in February 1966.

As shown in Fig. 12, at the 20A
station on the crater lip tritium concen-
trations at the 3-ft depth dropped from
1.1×10^7 to 2.5×10^6 dpm/ml in the period
from December 1965 to February 1966.
Although the record is not complete for
the 4-ft depth, a soil moisture maximum
was reached in August 1966, six months
after this high rainfall, and by August 1966
the tritium concentrations at the 4-ft depth
had also dropped slightly.

The return of the soil-water tritium
concentrations (6-in. to 3-ft stratum) to
their pre-rain levels had occurred by
September 1966, indicating replenishment
from some other source in the soil sys-
tem, presumably from the higher concen-
trations found at the 5- and 6-ft depths.
Rain also fell in the summer of 1966,
0.94 in. in July and 0.42 in. in August, but
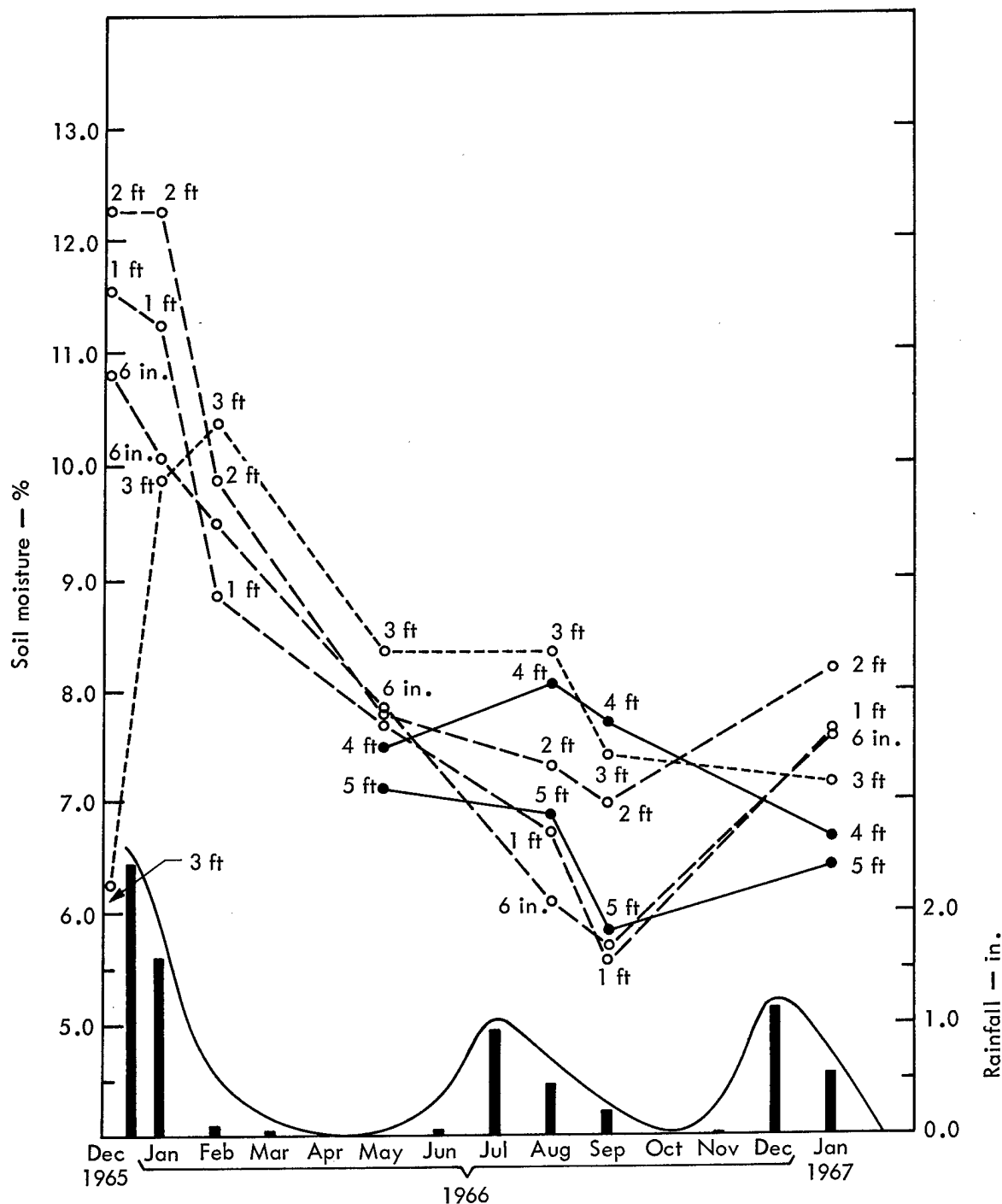during the period of maximum evaporation,

Fig. 14. Soil moisture variations for samples from 20A station (December 1965 to January 1967).

rain is apparently not effective in diluting the tritium concentrations even at the 6-in. depth, and did not influence the 6-in. soil moisture which continued to drop in August and September (Fig. 14).

The correlation of rainfall and soil moisture data with tritium concentrations during a period of unusually high rainfall and into a period of normal rainfall reveals a close relationship between

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environmental water fluxes and the soil-water tritium depth profile. When normal rainfall occurs (3.97 in./yr — five-year average) it is unlikely that dilution of soil-water tritium would take place below a 2- to 3-ft depth. The front of diluted water produced by the 1965-1966 rainfall definitely reached a depth of 3 ft, and six months later dilution at the 4-ft depth is evident. Zimmerman[7] studied the dynamics of a discrete tritium pulse injected into soil systems that have been recently disturbed and that are somewhat less permeable than those at the Sedan crater. Zimmerman found that the tritium front moved at a rate of less than 1 m/yr and was affected by both bulk flow and lateral losses to "stationary" water, held by capillary or chemical forces at the soil particle level. The reverse situation is present at the Sedan crater; in other words, a tritated soil-water system with a stable water pulse, but some of the general assumptions may be useful to our studies. The movement of the stable water pulse in Sedan crater lip soils is somewhat faster than the 1 m/yr observed by Zimmerman, but this rate may be attributed to (1) the recent disturbance of the soil system at the Sedan crater which has completely destroyed the original bulk density relationships, and (2) perhaps to the coarser, more permeable soil type at the Sedan crater.

In February 1967, a series of sample holes were dug along the 20A and 16A transect lines to obtain detailed information on the concentrations of tritium in the ejecta field at distances where ejecta is present as a shallow surface deposit in essentially undisturbed soil. Shock effects undoubtedly loosened the soil at these stations and increased the permeability to water. The soil-water tritium concentrations along these two transects are shown in Figs. 15 and 16.
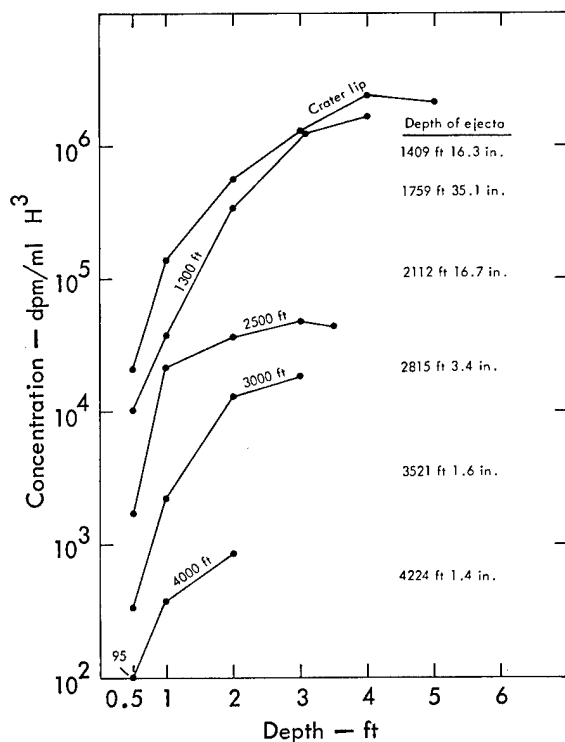

Fig. 15. Soil-water tritium concentrations for samples from 16A transect (February 1967).
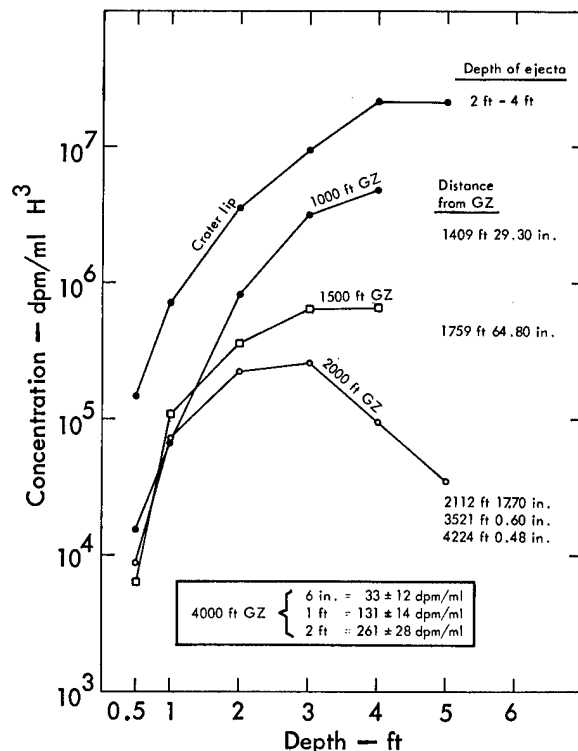
Fig. 16. Soil-water tritium concentrations for samples from 20A transect (February 1967).

Along the 16A transect, soil samples were taken at the crater lip, 1300, 2500, 3000, and 4000 ft from GZ. The 16A transect data are shown in Fig. 15 with depth-of-ejecta values taken from Carlson and Roberts[5] for the stations nearest to our sample holes. At 3000 and 4000 ft from GZ, where only a shallow layer (1 to 4 in.) of fine ejecta was deposited, tritium is present in soil water, increasing in concentration with depth, at least to 3 ft. The maxima in soil-water tritium found in these profiles at distances greater than 2500 ft are probably associated with the maximum penetration of rainfall in these soils, which is apparently less than that observed in the crater lip soil. Between 1300 and 2500 ft from GZ, a definite break occurs which is associated with the deeper mass-deposited ejecta (to 2112 ft). The similar profiles of the lip area and the station 1300 ft from GZ indicate that this zone of the throwout is essentially the same mass of earth as far as its detonation history is concerned. The crater-lip tritium profile exhibits maximum concentrations at the 4-ft depth, which is the depth of ejecta measured by Richards[4] at the southwest sector of the crater. The tritium profile in the overturned alluvium beneath the fallback or ejecta layer has not been determined, but it is quite possible that gaseous detonation products permeated this earth mass. The presence of glass blebs in the overturned alluvium strata below the fallback indicates some contact with and retention of detonation products. The tritium concentrations below the fallback depth may therefore be the product of water movement (liquid and gas) down from the fallback materials, or they could represent a lower level of

tritium scavenging by the overturned alluvium. The continued decrease in tritium concentrations that is seen at depths of 5 and 6 ft[*] may indicate that tritium in the overturned alluvium has been translocated there since the detonation; however, the profile is not complete enough to permit any definite statements about sub-ejecta tritium levels.

At 2500 ft where maximum tritium concentrations occur at 3 ft, the depth of ejecta is not greater than 1 ft, based on gross gamma radioactivity data, in the same samples from which tritium was extracted. At 3000 ft from GZ, gross gamma data indicate only a low level of radioactivity in the 6-in. stratum (10 cpm/g above preshot level), and the tritium concentrations reach a maximum concentration at 3 ft. The depth of ejecta at this point is between 1.6 and 3.4 in.

It is apparent that a valuable area of investigation is present in the portions of the ejecta field where a shallow layer of radioactive soil overlies the preshot native soil system. Here it is possible to determine those radionuclides which are mobile under natural conditions, and which usually are available to biological systems. Studies of the gamma-emitting and other beta-emitting radionuclides are being conducted in these areas and those data will be presented in a subsequent report.

In Fig. 16, tritium concentrations for 20A transect sample holes are shown with the depth of ejecta at various points on the transect. The intervals on the 20A transect are closer to the crater lip and indicate essentially the same relationship

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[*]See Fig. 25.

between the depth profile and distance from the crater. Apparently ejecta thickness is greater on the 16A transect because the profile for the station 1300 ft from GZ is very similar to the crater lip profile, while on the 20A transect the profile for the station 1500 ft from GZ indicates a leveling off of concentrations at the 3-ft depth, which would very likely decrease below that depth as they do at 2000 ft. The crater lip profile exhibits a flattening at the 4- to 5-ft depth, which is correlated with the expected maximum depth of ejecta in the 20A sector.

Ejecta thickness data are given in Table I for the 16A and 20A transects

TABLE I. Ejecta thickness at Sedan crater.

Distance from GZ (ft)	20A transect		16A transect	
	kg/m^2	cm	kg/m^2	cm
5599	1.27	0.08	7.71	0.51
4198	7.62	0.50	52.5	3.5
3500	23.1	1.5	62.1	4.1
2798	42.0	2.8	125.0	8.4
2099	229.0	15.3	626.0	41.7
1748	633.0	45.7	1280.0	85.3
1400	1100.0	73.2	610	40.8

and were taken from Carlson and Roberts.[5] The greater depth of ejecta at a distance of 4224 ft from GZ on the 16A transect has apparently resulted in the higher levels of tritium found in the soil profile at that point. On the 16A transect the ejecta is between 1 and 2 in. deep at 4000 ft, and the tritium concentrations are approximately three times those found at 4000 ft on the 20A transect, where ejecta was less than 1/2 in. deep.

It is possible that after the detonation, wind removed or translocated fine ejecta deposited at a distance of 4000 to 5000 ft from GZ. Aeolian effects on the distribution of ejecta were noted by Carlson and Roberts.[5] If rain occurred before the ejecta was entirely removed, the elution of ejecta-held tritium into the undisturbed soil system beneath would take place. It is also possible that some fine particulate ejecta filtered into the soil profile, but hardly to a depth of 2 ft. At 4000 ft there is very little material on the soil surface that can be identified as Sedan ejecta, and the general radiation level is quite low so that very little evidence of the Sedan detonation is present at the site.

In the February 1967 field study, two sample holes were dug at the 11A station on the crater lip to determine the variability of tritium there. The soil-water tritium concentrations for two pits dug 8 ft apart are given in Fig. 17. The variation between the two sets of data again indicates that the uncertainty in sampling a discrete depth stratum is about 3 in. ±.

In April 1967, soil samples were obtained at the following stations: 20A-crater lip; 20A-400 ft from GZ; 16A-crater lip; 16A-400 ft from GZ; and 11A-crater lip. In Fig. 18, the soil profile data for the 11A- and 16A-crater lip are compared for the period February to April 1967. The comparison is made because the two profiles seemed to be at variance with each other with respect to rainfall effects. The 6-in. depth at the 16A station showed a definite lowering of tritium radioactivity in April which was caused by 0.67 in. of rain. This amount of rain apparently did not affect the 1-ft depth at the 16A station,
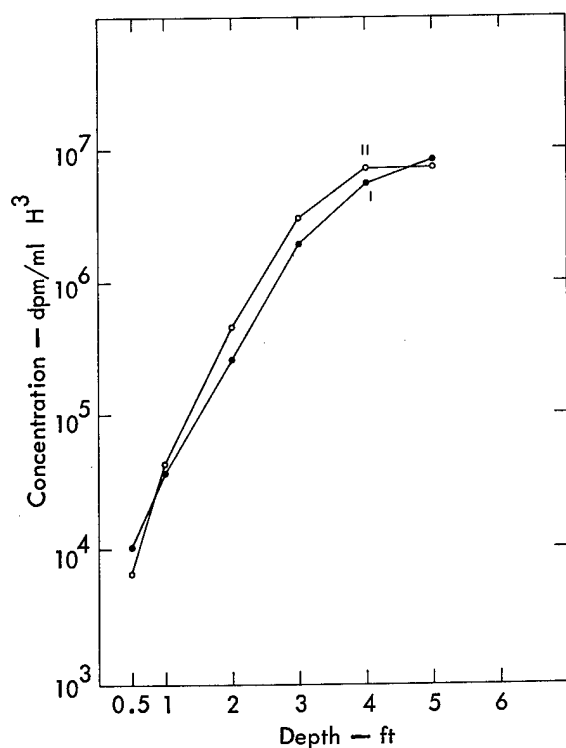
Fig. 17. Comparison of soil-water tritium concentrations for samples from 11A station on crater lip (February 1967).
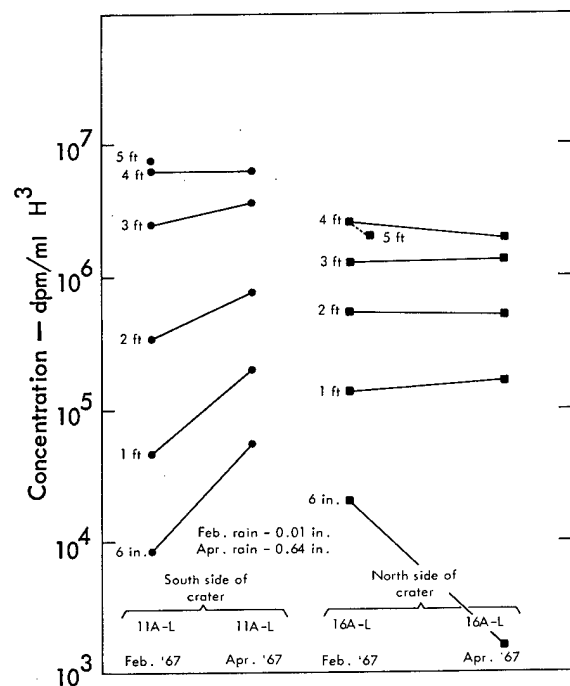

Fig. 18. Soil-water tritium concentrations for samples from 11A and 16A stations on crater lip (February to April 1967).

however. At Station 11A, the reverse situation appears to have taken place in the same time period, and an increase of radioactivity was measured in April. The only difference between the two stations is that 11A is a south-facing slope while 16A is a north-facing slope of the crater. At 16A snow is often found in the winter where it persists for several days in the cooler microclimate that apparently exists on the north slope of the crater. North and south slope differences are quite common in ecological relationships between organisms and their microclimates. The greater insolation received on the south-facing slope of the Sedan crater has caused a more rapid depletion of the soil water as early as April so that the site appears to be already in the portion of the year when evaporation losses are occurring. A small increment of rain had no effect at this site on the THO concentrations in the 6-in. stratum of the soil.

In April 1967, soil sampling holes were dug at the 20A and 16A crater lip sites, and at 400 ft from the crater lip on each of these transects. The April 1967 soil-water tritium data are shown in Fig. 19. The depth of the ejecta at the crater lip stations is on the order of 3 to 4 ft for the 20A station and approximately 3 ft for the 16A station, according to Richards.[4] The sample holes therefore transected the ejecta layer at both stations. At the 16A station 800 ft from GZ, the ejecta depth was measured at 16.3 in. while at the 20A station 800 ft from GZ, the depth was 29.3 in. (Carlson and Roberts[5]). However, both transects of close-in ejecta show reduced concentrations of tritium at 400 ft, expecially the 16A transect where concentrations are more than an order of
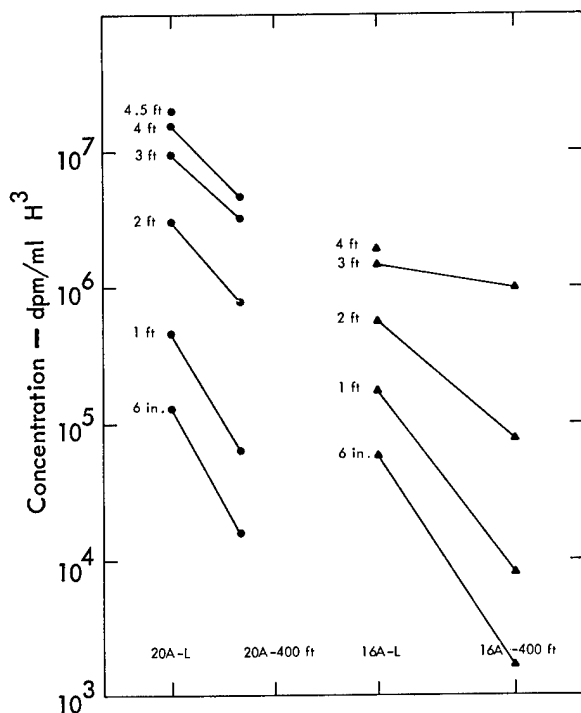
-22-

Fig. 19. Soil-water tritium concentrations for samples from 20A and 16A transects (April 1967).

magnitude lower at the 6-in. and 1-ft depths. On 20A, the 6-in. and 1-ft depths are 12 to 14% of the crater-lip tritium concentration at the same depths. Ejecta thickness values, shown in Table I, indicate almost twice the depth of ejecta on the 20A transect 800 ft from the crater (1400 ft from GZ) as was found on the 16A transect 1400 ft from GZ (73.2 cm vs 40.8 cm). On the 20A transect of the ejecta there are higher tritium concentrations nearer to the crater due to greater ejecta thickness, while on the 16A transect low levels of tritium are found at greater distances from the crater because fine ejecta (missile-ejecta) was deposited farther along that transect line.

When detailed study is made of tritium concentrations in the ejecta field, variations are evident, some of which are un-doubtedly related to depositional differences and other which are due to ecological effects that have taken place since the detonation. There are no baseline tritium concentrations for ejecta immediately postshot available for comparison, and therefore it is difficult to evaluate the data obtained from sporadic, discontinuous readings. By maintaining a program of continued sampling, it is possible to determine those present variations that are related to recurring climatic factors and those that may be caused by basic depositional differences.

It is now apparent that the distribution of tritium in soil water at the crater lip is not isometric. The northwest edge of the crater has low concentrations, while the western segment of the lip has very high concentrations, in excess of 10^7 dpm/ml of soil water. Perhaps the differences are small but they have been found repeatedly and are therefore part of the distributional pattern. During the course of a typical climatic year, tritium concentrations fluctuate in the stratum from the surface to a depth of 3 ft by more than an order of magnitude, both in the crater lip and in the more distant ejecta. Where the ejecta has been deposited as a shallow layer on the surface of the preshot native soil, maximum tritium concentrations are found in the native soil profile, usually near the 3-ft depth, which is approximately the maximum depth of penetration of rainwater in undisturbed desert soils in this area. Some microclimatic effects may be seen in the variations in soil water and THO concentrations for a specific site.

More detailed information on the distribution of tritium in the area 500 ft from the crater lip to 4000 ft from GZ was

sought to provide data on the region where ejecta begins to thin out and constitutes a shallow discrete layer overlying the native soil. In June 1967, two detailed transects of the ejecta field were made along 20A and 16A transect lines to a distance of 2500 ft from GZ on 20A and to 3500 ft from GZ on 16A. The soil-water tritium concentrations determined in the June 1967 samples are shown in Figs. 20 and 21.

In Fig. 20, data from the 20A transect indicate that at 500 ft from the crater lip there is no increase in tritium concentration at depths between 4 and 5 ft where the ejecta thickness is probably not much nearer the surface than at the crater lip. However, concentrations at 500 ft from the crater lip are lower than at the crater lip site even though the ejecta thickness

is comparable and the same leveling-off of concentrations occurs between 4 and 5 ft. The sample hole is not deep enough at 1000 or 1250 ft from the crater lip to determine whether or not part of the profile is below the ejecta layer. But the sampling station 1500 ft from GZ was dug to a depth of 6 ft and provides a good profile of tritium distribution where ejecta overlies nonradioactive soil. Peak tritium concentrations occur at a depth of 3 ft at the stations 1500 and 2000 ft from GZ, and at a depth of 2 to 3 ft at the station 1750 ft from GZ.

In Fig. 21, soil-water tritium profile data are presented for the 16A transect. The decrease in tritium concentrations below 3 ft occurs at 1250 ft on the 16A transect, which as we have seen, has a
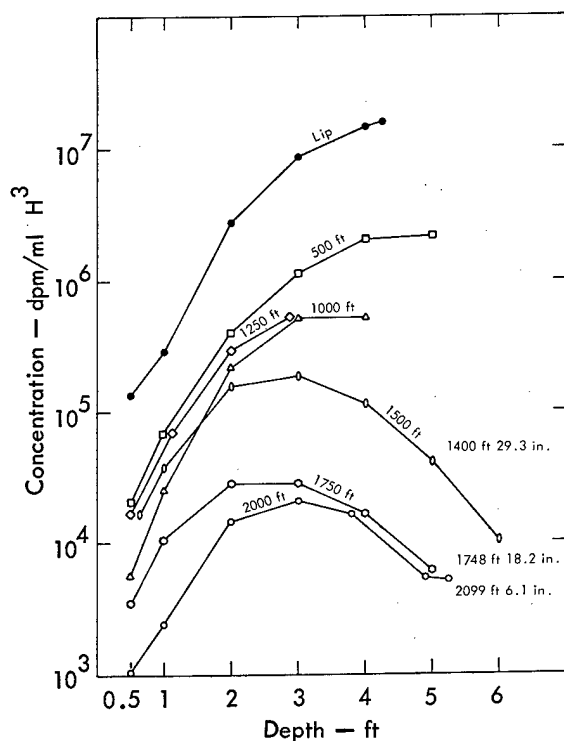
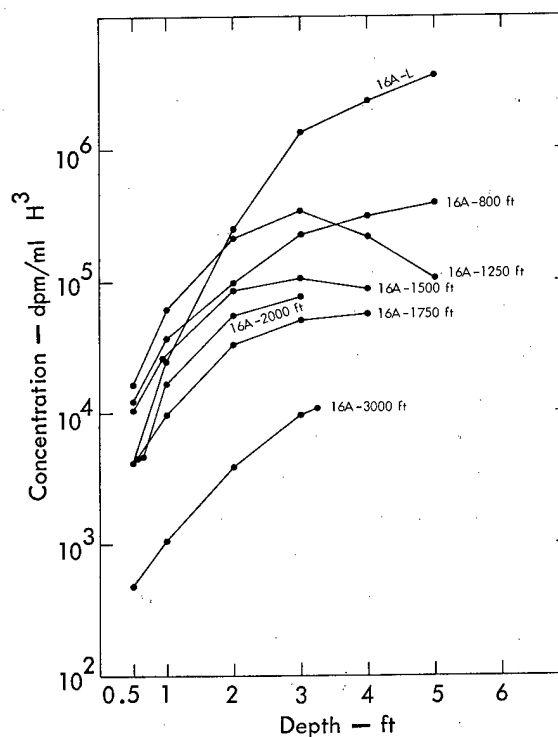Fig. 20. Soil-water tritium concentrations for samples from 20A transect (June 1967).

Fig. 21. Soil-water tritium concentrations for samples from 16A transect (June 1967).

shallower deposit of ejecta at these distances from GZ. From these data obtained at the edge of the bulk-ejecta area, it appears that soil profiles with depth-concentration curves (which begin to decrease at or near 3 ft) have leached tritium in the soil water. The steady increase of tritium concentrations with depth, as seen at the crater lip and 500 to 600 ft from the crater, is characteristic of deep ejecta in which initially high concentrations of soil-water tritium have been diluted in the surficial strata by rainwater but where increasing concentrations occur throughout the profile.

Relationships of Soil-Water Tritium and Gross Gamma Radioactivity

In addition to utilizing the ejecta depth measurements made shortly after the detonation, we may consider the gross gamma radioactivity in the ejecta as a "tag" whereby another estimation of the present ejecta depth can be made. Gross gamma radioactivity expressed as counts per minute per gram (cpm/g) of dry soil, as determined with a 4-in. NaI scintillation crystal detector with discriminators set to detect energies from 0 to 2.0 MeV have been utilized to estimate the depth of ejecta in the 20A and 16A transect data. Tritium concentrations are plotted in Fig. 22 with gross gamma radioactivity for five of the soil-water tritium profiles shown in Fig. 19.

The crater lip gamma and tritium radioactivity correlate well in that the highest levels of each are present at the same place. Gross gamma radioactivity measurements were made on the same 250 to 350 g of soil from which the tritium was

extracted, and counted in a constant geometry.

At 1000, 1500, and 1750 ft, gross gamma radioactivity decreases rapidly with depth below the 1-ft stratum, and at 4 ft is barely above the NTS soil gamma background. At the 2- and 3-ft depth at 1000 and 1500 ft, a small amount of gamma radioactivity is present above background and probably represents radionuclides translocated vertically in the undisturbed soil system. Gamma radioactivity is being determined and quantified, and these data will appear in a future report.

Correlation of tritium concentrations with gross gamma radioactivity, as in Figs. 22 and 23 (16A), demonstrates that maximum tritium concentrations may be found in a soil stratum containing very little gross gamma radioactivity. Gross gamma radioactivity decreases rapidly from the 6-in. to 1-ft stratum to levels near background at 2 or 3 ft beyond 1250 ft from the crater. In deep ejecta, gross gamma radioactivity remains high throughout the soil profile and usually higher specific radioactivities are found at or near the surface. The 20A-crater lip profile for gross gamma radioactivity is an exception to this, and the 4.5-ft depth gross gamma radioactivity is almost twice that found at 6 in.

It is apparent from the data shown in Figs. 22 and 23 that the vertical distribution of tritium and gross gamma radioactivity are the reverse of each other in most cases on the crater lip, and in all cases at some distance from the crater. The tritium profile is the product of post-shot environmental factors and depositional effects while the gross gamma radioactivity profile is mainly due to depositional factors
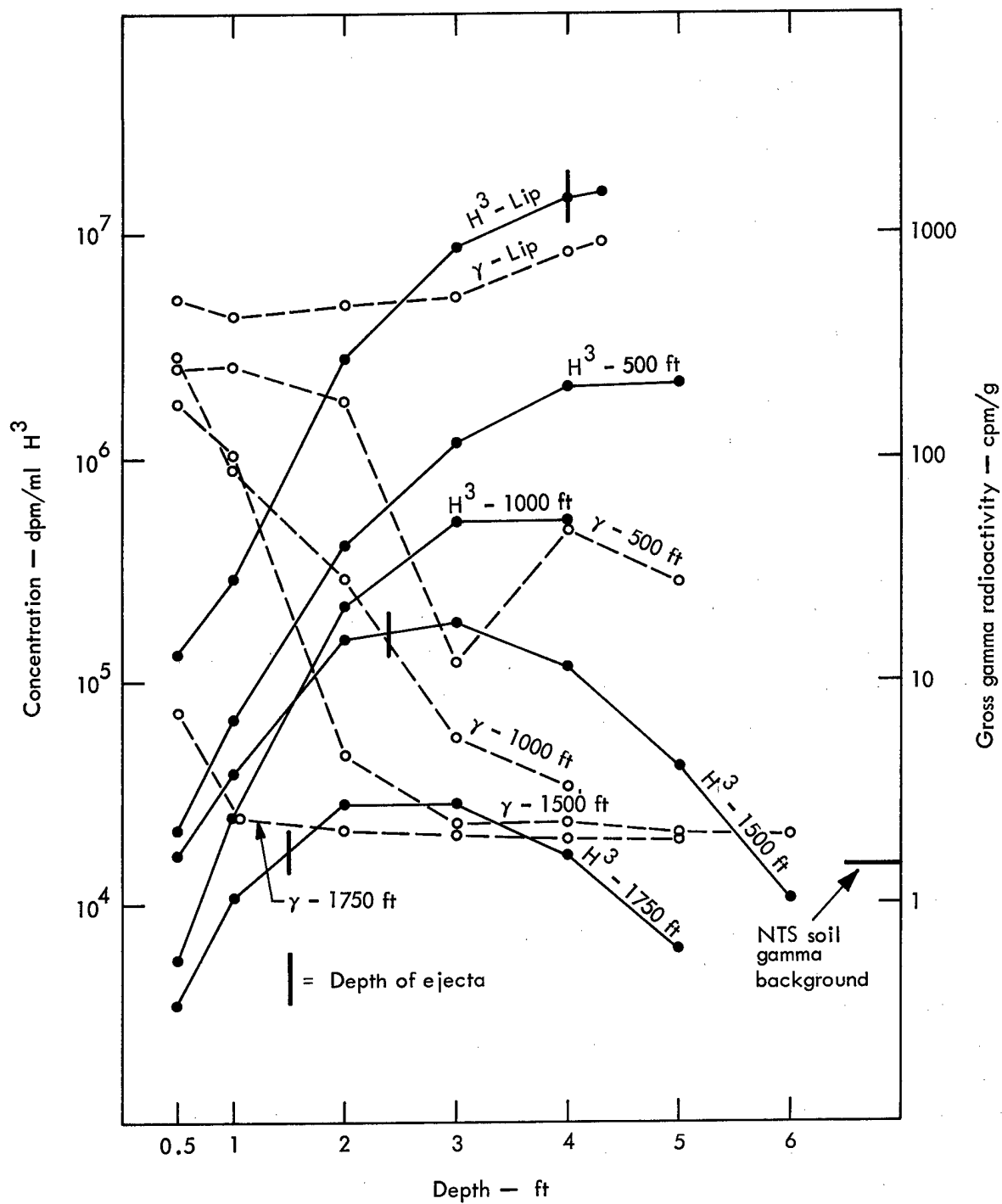
-25-

Fig. 22. Soil-water tritium concentrations and gross gamma radioactivity for samples from 20A transect (June 1967).
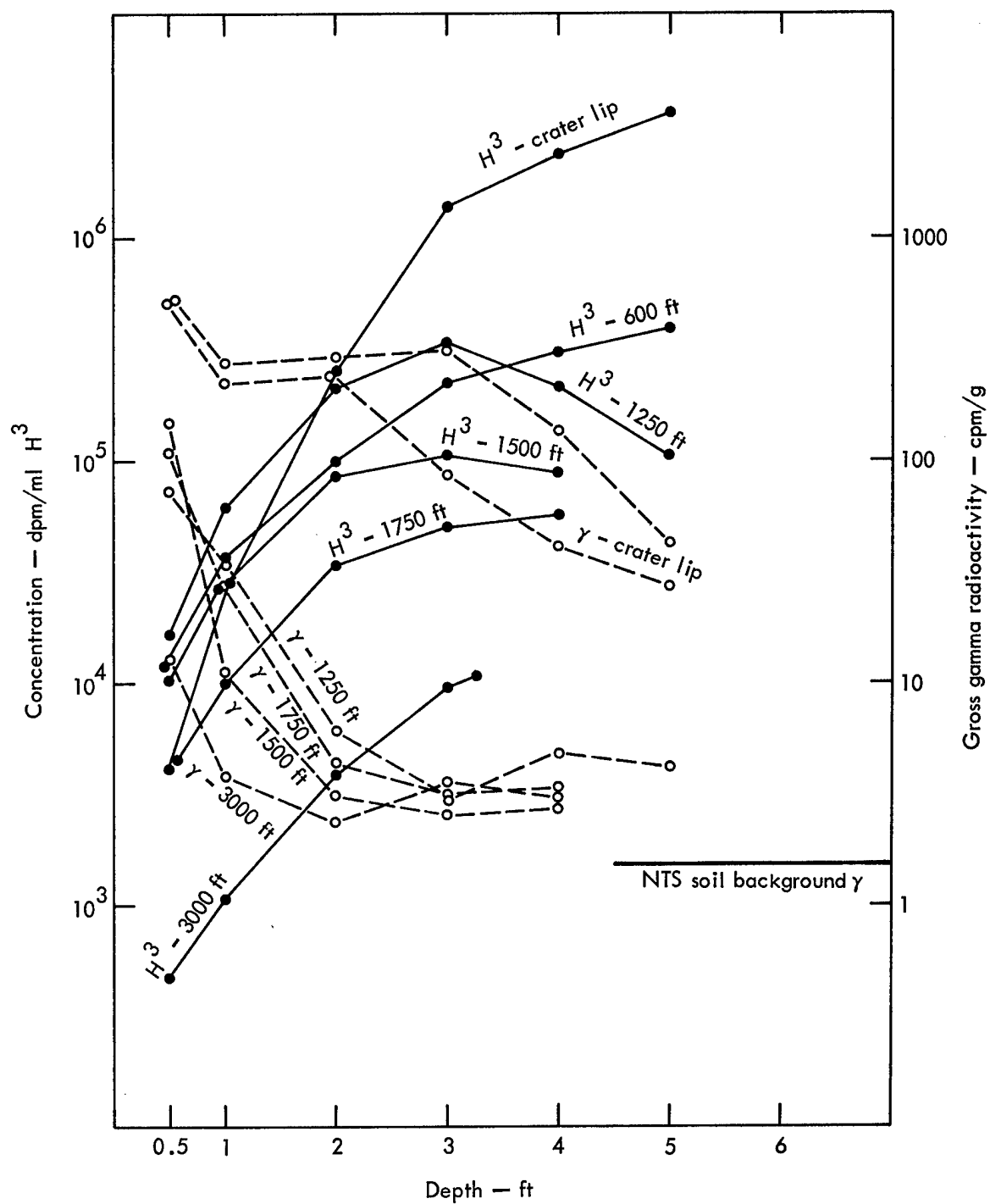
Fig. 23. Soil-water tritium concentrations and gross gamma radioactivity for samples from 16A transect (June 1967).

with a small amount of secondary movement indicated by gross gamma radioactivity below the ejecta layer. Current studies will reveal the qualitative and quantitative nature of these mobile radionuclides.

Tritium and gross gamma radioactivity data in Figs. 22 and 23 pertain to the 20A crater lip sector, which is somewhat higher in both types of radioactivity than other sites, and to the 16A sector which is in the low range of tritium concentrations. In Fig. 24, all of the sectors of the
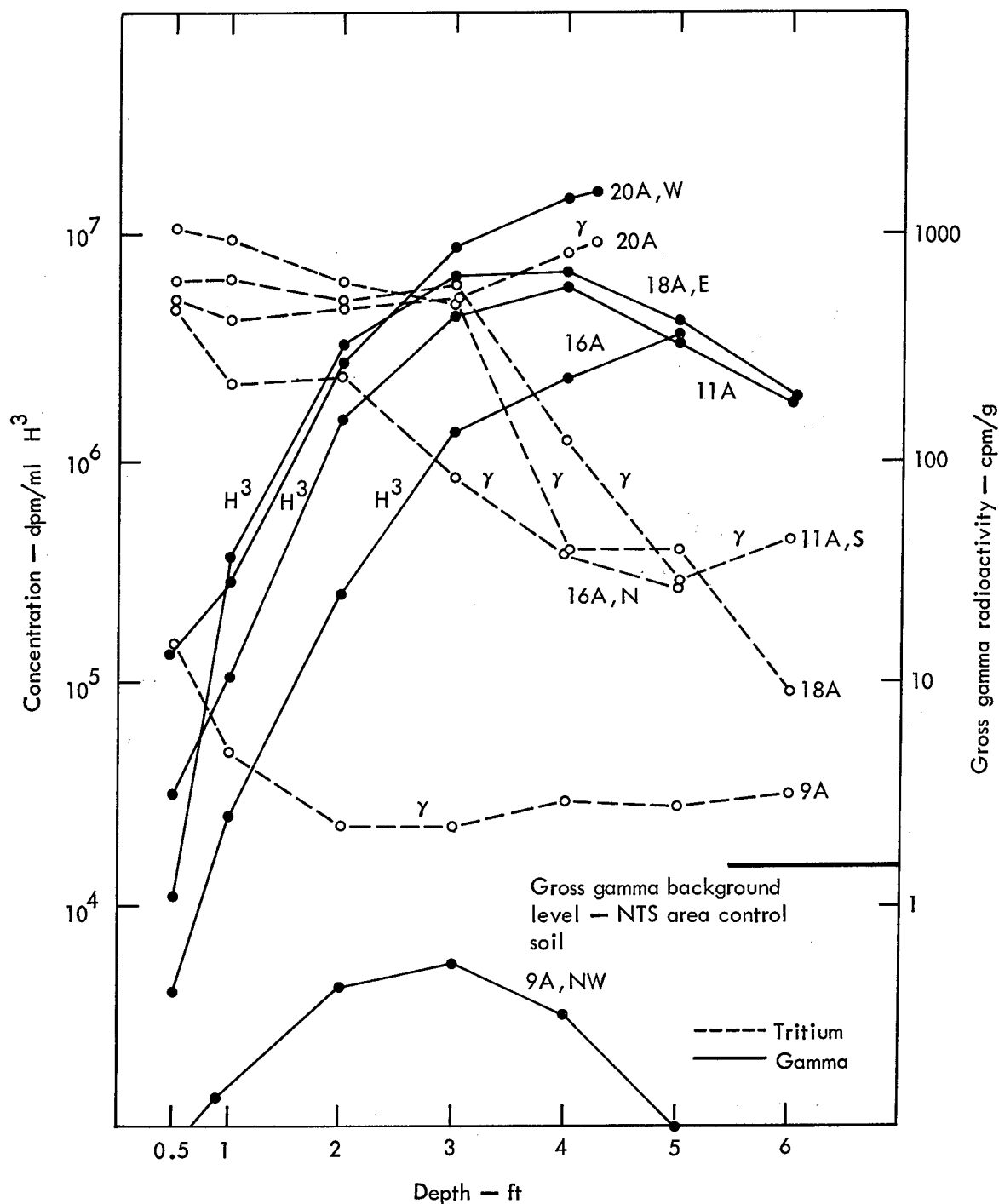

Fig. 24. Soil-water tritium concentrations and gross gamma radioactivity for samples from all sectors of crater lip (June and July 1967).

crater lip under study are shown with their tritium and gross gamma radioactivity profiles to depths of 5 or 6 ft. These data were obtained in June and July 1967. The 20A sector is apparently unique in that it is the only portion of the crater where an increase of gross gamma radioactivity is seen with depth, and tritium concentrations at 4 ft are higher than at any other site. The 11A, 18A, and 16A sectors, embracing the eastern half of the crater lip, are quite similar except that the 16A sector, on the northern edge of the crater, is lower in tritium and also has lower gross gamma radioactivity at depths from 1 to 3 ft. At the 5-ft depth, 11A, 18A, and 16A samples have essentially the same gross gamma radioactivity. The 9A sector has low tritium concentrations and low gross gamma radioactivity. The correlation that seems to be evident in these data is that there is a relationship between tritium distribution and gross gamma radioactivity in the crater lip ejecta. The reason for the decrease in gross gamma radioactivity with depth at a majority of the crater lip stations is not evident in these data. This pattern is probably not caused by any environmental influences because there is little evidence for any large scale translocation of gamma-emitting radionuclides elsewhere where it would be more obvious. If the gamma-depth profile is due to depositional phenomena, it may be related to variations in the scavenging of radioactivity by different kinds of ejecta, either missile- or bulk-ejecta. A stratification of the ejecta layer is evident with the missile-ejecta occurring at the surface where most of the gross gamma radioactivity also is found.

Summer 1967 Data

In July 1967, soil samples were collected along the 18A transect, east of the Sedan crater. Seven soil holes were dug at 500, 1000, 1250, 1500, 1750, and 2000 ft from the crater lip to a depth of 5 or 6 ft. Soil-water tritium concentrations for the 18A transect series are shown in Fig. 25.
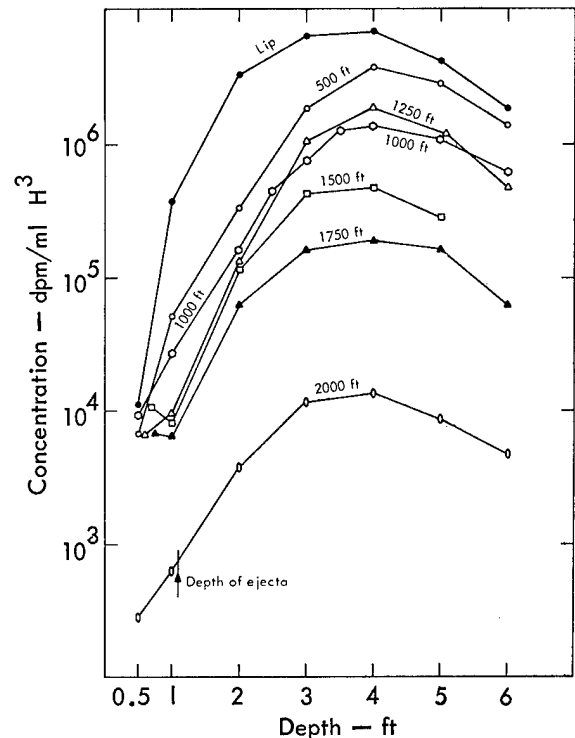

Fig. 25. Soil-water tritium concentrations for samples from 18A transect (July 1967).

Crater lip concentrations decrease below the 4-ft depth and so do concentrations at all other stations in this series. This was not seen in the other transect profiles which were sampled at similar intervals (Figs. 20, 21, and 26).

This series of sample holes has yielded the most regular sequence of data on tritium concentrations in the ejecta field.
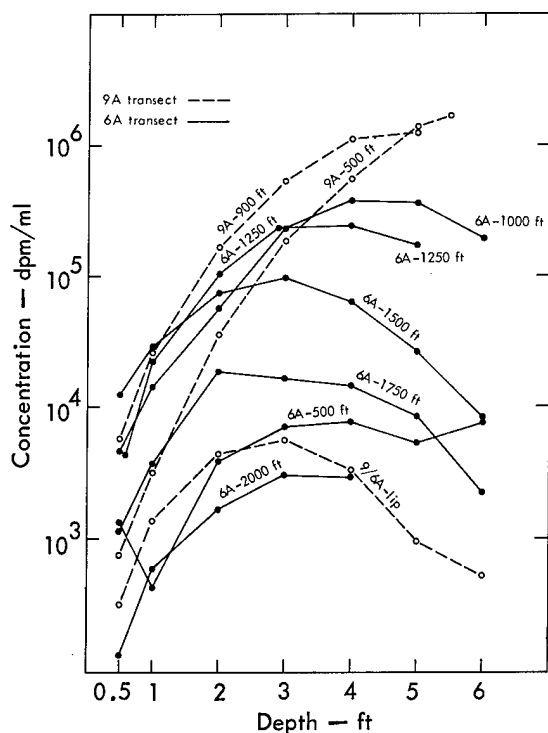
-29-

Fig. 26. Soil-water tritium concentrations for samples from 6A and 9A transects (July 1967).

The decrease in tritium concentration at a 4-ft depth on the crater lip with very little increase from 3 to 4 ft indicates a depth of ejecta or fallback of 3 to 4 ft. This is in the range of depths given by Richards[4] for this sector of the crater. The 18A-crater lip profile, extending 2 to 3 ft below the ejecta layer, characterizes the distribution of residual tritium in the earth mass moved by the detonation after five years of environmental effects. All tritium below 4 ft has been translocated there by one or more processes, including the effects of the unusually high rainfall in the winter of 1965-1966. Vapor transfer, capillary water movement, and self-diffusion are processes that conceivably could account for THO movements at depths of 4 to 6 ft in the desert environment of North Yucca Flat. There is no

percolation of water through the soil profile to any ground water system or even below 3 ft during years of normal rainfall because of the small amount of rainfall received. Therefore, any large-scale mass movements of soil water which could account for tritium below the ejecta layer at 6 ft are precluded. Perhaps we should not overlook the possibility that tritium can be retained by the overturned alluvium as well as the ejecta.

The similar decrease of tritium concentration occurring at 4-ft depth at all sites, regardless of the depth of ejecta, leads us to believe that the same factor produced the tritium depth profile at all of the stations. This factor is soil-water percolation or leaching. At 2000 ft from the crater, the ejecta depth is 13+ in. and maximum tritium concentrations occur at 4 ft. All the tritium below 13+ in. therefore was translocated there by soil-water movement.

There are lower concentrations at 2000 ft because the bulk ejecta layer is no longer present at this distance from GZ. The outer limits of the bulk-ejected throwout in the area of the 18A transect is approximately 600 m or 1980 ft (as measured in Fig. 3.5 from Carlson and Roberts[5]), which is very close to the 2000-ft station whose soil-water tritium profile is shown in Fig. 25. Most of the tritium in the profile from Station 18A 2000 ft from GZ has been eluted there from a superficial deposit of missile-ejecta materials. The depth of ejecta in this area was measured by Carlson and Roberts[5] at 40.0 cm or 16 in.

In July 1967, the area at the north-northwest edge of the crater was sampled. Soil sample holes were dug to a distance

-30-

of 2000 ft on the 6A transect, which has its crater lip station on the highest point on the crater lip. The 9A- and 6A-crater lip stations are very close and only one sample hole was dug. The 9A-6A transect data are shown in Fig. 26. The profile curves do not occur in a regular sequence in this figure because the crater lip and more distant sample site data occupy the lower part of the figure due to the fact that lower concentrations of tritium were found in both of those areas. The 9A-6A crater lip station has lower tritium concentrations than are found at distances of 1500 to 1750 ft from the crater. Along the 6A transect (the more westerly of the two) low concentrations are found at 500 ft from the crater also. On the 9A transect, on the north side of the mound, tritium concentrations increase by more than an order of magnitude at 500 and 900 ft. The typical decrease in radioactivity in the stratum 2 to 5 ft takes place as distance from the crater increases.

In general, the usual relationship of tritium concentrations in the soil profile with distance from the crater is not present in the 9A-6A transect area, and presumably because of the unique history of the mass of earth forming this mound. Nordyke and Williamson[8] described certain anomalous movements of a mound of earth lifted by the detonation at 15 deg west of north which resulted in the high point on the crater lip at 9A. Richards[4] noted that there was no appreciable amount of ejecta or fallback on this prominence and our measurements clearly demonstrate that at least smaller amounts of ejecta were present in this area. Compared to other portions of the lip, the 9A station has both lower tritium and gross gamma

radioactivity in the soil profile. It is apparent therefore that specific details in the phenomenology of a nuclear cratering detonation may affect the distribution of radioactivity in the mass of earth moved by that detonation, in this case, in a manner so that an appreciable reduction in radionuclide concentrations was affected. If little or no ejecta is present on the 9A mound or slump area, as indicated by Richards, and the soil in that area is composed of the preshot ground surface, the occurrence of 10^3 to 10^4 dpm/ml of tritium in soil water at a depth of 6 ft indicates some level of exposure of the earth mass to gaseous detonation products. The very low gross gamma radioactivity of the surface soil at Station 9A, and the even lower levels from a 2- to 6-ft depth would indicate a very limited contact with most of the radioactive detonation products. If a gaseous radionuclide such as tritium is injected into earth materials even though they are not intimately involved in the detonation, we might also expect to find other radionuclides with gaseous precursors in this soil mass. The determination of gamma-emitting radionuclides in the soil sample from which tritium was extracted may yield some information on this subject.

SEASONAL SOIL-WATER TRITIUM VARIATIONS

In the body of this report, soil-water tritium data obtained from many sampling periods have been presented and briefly discussed. Although at each point in time where samples were obtained, some useful purpose was achieved by the individual sample series, the greatest value lies in the perspective provided by an integrated

series of analyses of the same parameter through time. This is certainly true of ecological events in which phenological patterns may provide the key to the functioning of the entire ecosystem. To this end, the soil-water tritium data have been compiled for certain sites in the Sedan study area where the time span of data is great enough to afford some radioecological perspective.

In Fig. 27 the soil-water tritium concentrations for the 20A station are plotted for the period December 1965 to June 1967. Also, monthly rainfall is shown on the horizontal axis on a linear scale. The large flux of rain in late 1965 and early 1966 apparently had already begun to lower soil-water tritium concentrations in December 1965. The 6-in. and 1-ft depths had already experienced some dilution by this time. When gravitational water is present in these disturbed, coarse soils with low clay content, drainage is fast, and within two months, dilution
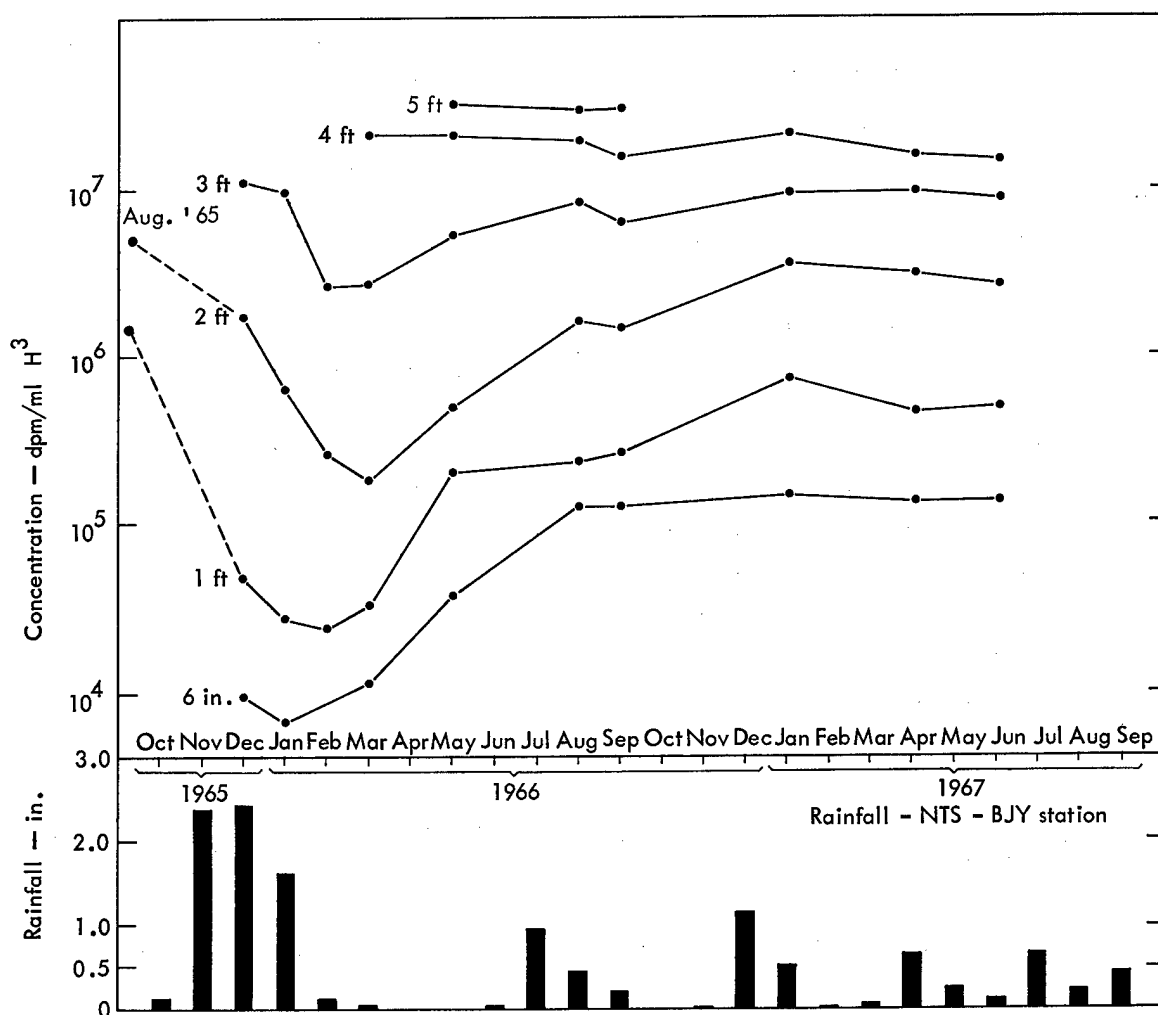

Fig. 27. Soil-water tritium concentrations for samples from 20A station on crater lip (1965 to 1967), showing rainfall.

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effects are observable at the 3-ft depth (March). The steep slope of the return to predilution concentrations, especially from 6 in. to 2 ft, would indicate a slow diffusion upward (February to August), probably aided by moisture deficits created in the surface stratum by evaporative and plant uptake losses in the spring and summer.

Two soil-water tritium concentrations, plotted on the left-hand margin of Fig. 27, represent samples collected in August 1965. The pre-rain period of the soil-water tritium dilution at the Sedan crater is not well documented, but by comparing the two 1965 values with the rest of the soil-water profile we can visualize the rest of the pre-rain profile. By late summer and fall in 1966 the soil-water tritium profile had become stabilized again after the 1965 high rainfall. Some gains in disintegrations per minute per milliliter were seen even in the winter of 1966 at the 1-, 2-, and 3-ft depths. The winter rainfall in December 1966 and January 1967 apparently did not affect the soil-water tritium concentrations for the 20A station, which is on the western edge of the crater. It appears that losses occurred during this period of measurements at the 1- to 4-ft depths, but to determine this, we must convert the data to disintegrations per minute per gram of soil to avoid confusing soil moisture variations with radioactivity concentration changes.

To evaluate the actual conditions of the decrease and rise in tritium concentrations that took place between March and August 1966, the disintegrations per minute per milliliter shown in Fig. 27 have been converted to disintegrations per minute per gram of dry soil using the percent moisture

values for those samples. The most obvious increase in tritium radioactivity occurred in the 6-in. to 3-ft stratum; however, disintegrations per minute per gram are given for the entire soil profile in Fig. 28. The total increase in tritium concentration as disintegrations per minute per gram of dry soil for each depth is shown on the right-hand margin of the figure. The greatest increase in disintegrations per minute per gram occurred at the 2-, 3-, and 4-ft depths where the maximum effect of the rainfall was seen in the reductions from the pre-rain concentrations. The total increase in the disintegrations per minute per gram in the 6-in. to 4-ft stratum is equal to 7.88×10^5 dpm/g or $0.35 \ \mu Ci/g$. This increase on an areal basis is 15 mCi/ft^2 at the 20A station. Under the conditions of this unusual rainfall, the 6-in. to 4-ft stratum may be
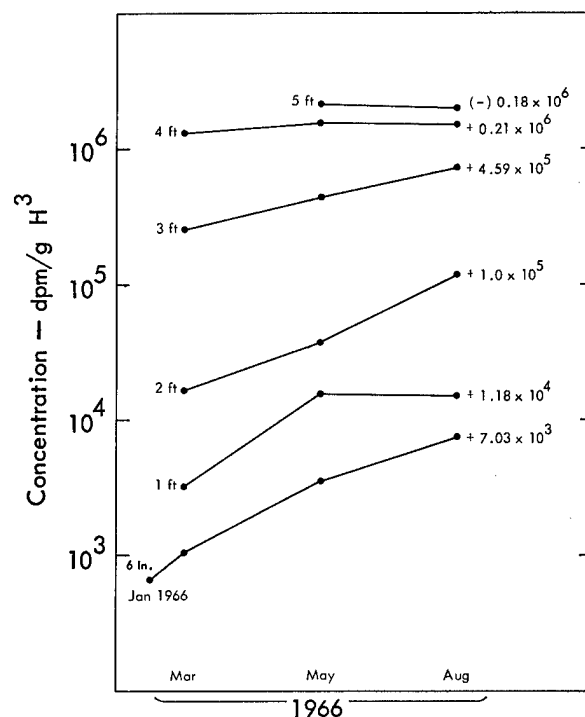

Fig. 28. Soil-γ tritium concentrations for samples from 20A station on crater lip, showing post-rain increases.

considered an active zone of tritium move-
ment wherein dilution, evaporation losses,
and plant uptake occur, and replacement
by vertical soil-water and vapor move-
ments takes place.

If the general trends in the depth pro-
file (shown in Fig. 27) for pre- and post-
rain tritium concentrations are compared,
it can be seen that replacements (shown in
Fig. 28) did not equal losses in the parts
of the system measured. Therefore, the
increase in tritium radioactivity observed
in the active zone of tritium move-
ment does not reflect the actual input-
output conditions that were operative in
the system. By using the pre-rain values
to calculate dpm/g tritium concentrations
before the dilution, and performing the
same operation for the depth profile at the
time of maximum dilution in March 1966,
a gross loss can be calculated on a dis-
integrations per minute per gram basis
for the 1-, 2-, and 3-ft depths. Subtract-
ing the gross loss from the gross gain
value, shown in Fig. 28, we obtain a net
loss value for tritium at the 20A station
as the result of three times the normal
rainfall. This value is approximately
11.5 mCi/ft^2 at the 20A station which has
higher concentrations than those determined
at other crater lip stations. Some of the
others are lower than those at the 20A
station by a factor of 2; therefore, to
enable calculation of the losses of tritium
from the entire crater lip area we must
adjust the loss to a value more representa-
tive of the entire crater lip mass. A value
of 5.7 mCi/ft^2 will be used as a represen-
tative estimate of the average tritium
losses of the crater lip area, based on the
actual measured loss at the 20A station
and on the relationship of the tritium con-

centrations found at the other stations to
the 20A station.

In Fig. 29, the μCi/ft^2 loss values are
plotted for the crater lip 600 ft from GZ,
1200 ft from GZ, and 1700 ft from GZ,
and a line is fitted to these points. The
integrated loss in μCi/ft^2 for the crater
lip to 1700 ft from GZ during the period
of unusual rainfall was calculated from
this line and is equal to 7.40×10^3 Ci.
This value probably has an error of $\pm$ 50%.

Based on the available data concerned
with soil-water tritium concentrations and
soil-moisture content, a loss of tritium
due to an unusual flux of rain at the Sedan
crater has been estimated. This loss has
been calculated by using disintegrations
per minute per gram values for the period
before, during, and after the rainfall. The
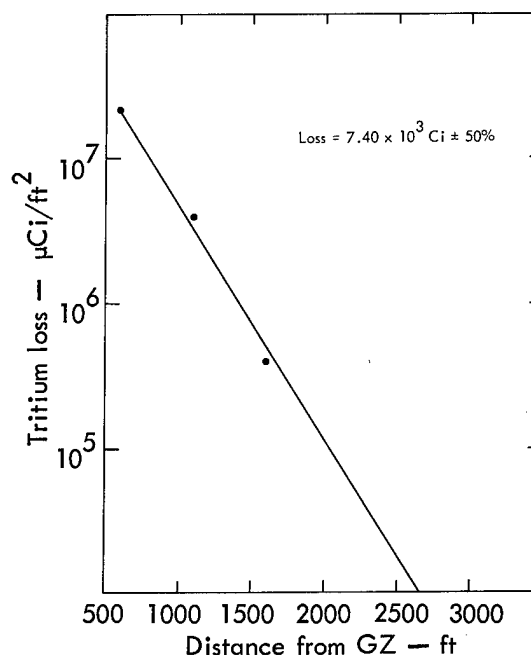values not actually replaced at three depths

Fig. 29. Tritium loss estimates
(1965-1966).

were considered as losses. The nature of the losses was not actually known, but, based on typical hydrologic cycle principles, the major losses are most likely evaporation and evapotranspiration. Certainly no losses occur into groundwater, which in this area is between 2500 to 3000 ft below the surface of the ground. The area of the Sedan ejecta field involved in this calculation includes the most significant portion of the land surface covered by ejecta from the Sedan detonation from the standpoint of residual tritium distribution. The concentrations occurring outside this area would not contribute a very large amount to a loss estimation.

To provide the necessary frame of reference, it would be useful to have data which would enable a calculation of tritium loss during the normal sequence of events; i. e. , when only 3 to 4 in. of rainfall occurs. The unusual amount of rainfall in the winter of 1965-1966 produced effects which resulted in the loss of tritium from the Sedan ecosystem many times the actual increase in precipitation. As more data are obtained, it may be possible to estimate the loss of tritium in the Sedan ecosystem under more typical conditions.

It is unlikely that comparable losses of tritium occur during a year of normal rainfall at the Sedan crater as were estimated above. The tritium concentrations shown in Fig. 27 for the winter of 1966-1967 and into the summer of 1967 show no large reductions, even in the shallow strata at 6 in. or 1 ft after the winter rainfall.

Although soil-water tritium records are not as complete for other stations as for the 20A station, the effects of this unusual rainfall and the seasonal pattern of soil-water and tritium variations can be seen in those areas as well. In Fig. 30, the soil-water tritium concentrations at the 16A crater lip station are shown with rainfall plotted on the horizontal axis. A microclimatic difference between this north slope station and other crater lip stations has been recognized and is evident in this 16-month record.

The lowest concentrations measured at 16A occurred in August 1966 five months later than those at the 20A station. It is possible that the 0.94-in. of rain received in July 1966 affected the downward trend of the tritium concentrations at 16A, but no such effects were seen in the summer at the other stations, and the concentration decrease involved all strata to 4 ft. Therefore, it is assumed that this dilution trend is the product of the same flux of rain which affected the 20A station and which is shown in Fig. 27. Evaporation losses may not be as great at the north-facing 16A station, and this pulse of stable water was more effective in that microclimate. A comparison of the tritium depth profile data for both stations indicates that the maximum effect of dilution of soil-water tritium at these stations occurred at different times.

The winter rainfall of 1966-1967 apparently caused more dilution at the 16A station than at the 20A. Marked decreases in tritium concentrations were seen at 6 in. in April 1967 and at 1 and 2 ft in June. The concentrations at 3 ft were not affected during a normal winter rainfall period; at least by June 1967 no effect was seen at the 3-ft depth. The rainwater penetration studies conducted by Rickard and Murdock[9] in Northern Yucca Flat soils during years of normal rainfall
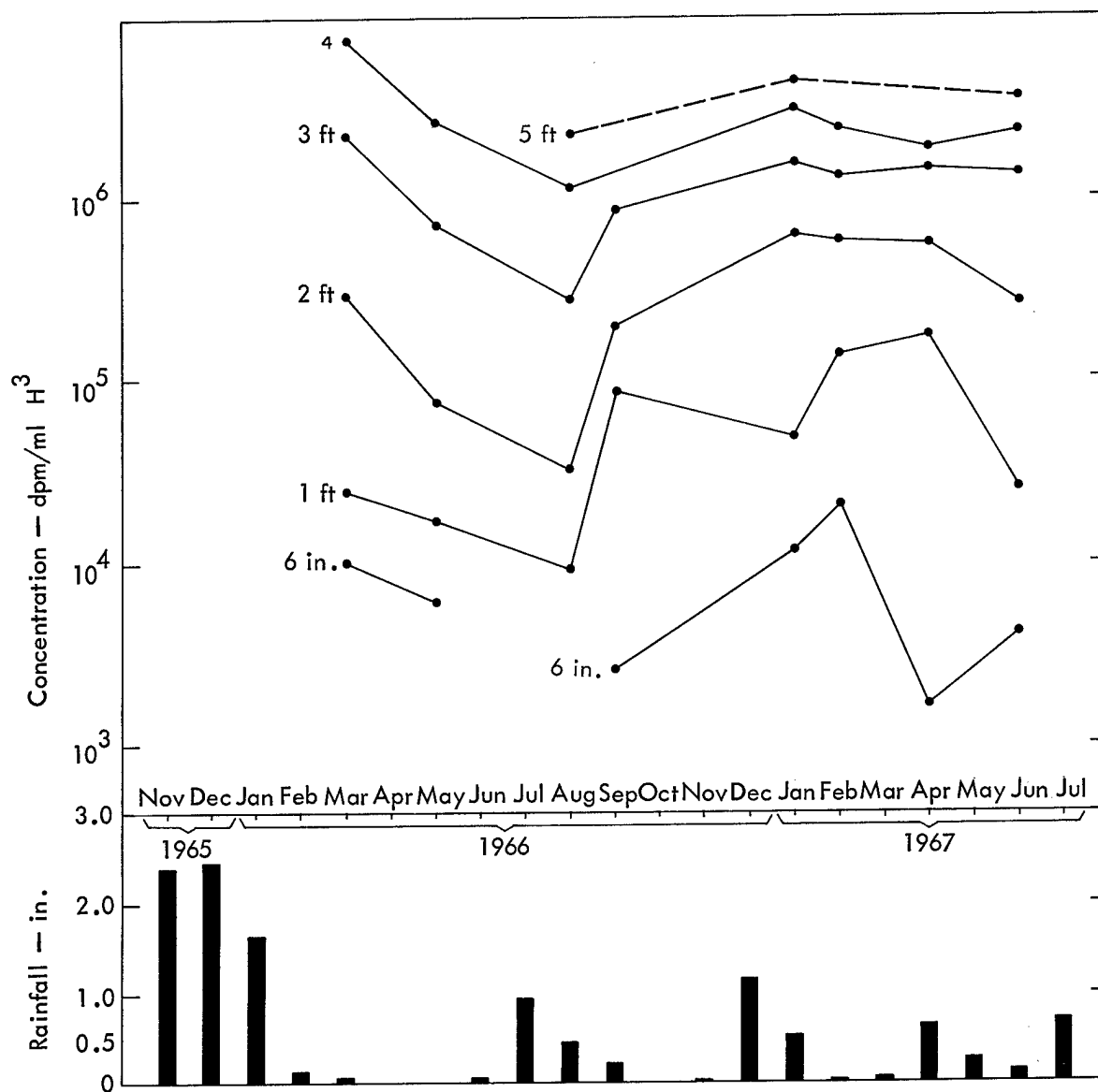
Fig. 30. Soil-water tritium concentrations for samples at 16A station on crater lip (1965 to 1967), showing rainfall.

indicated that 24 in. was the maximum depth to which rainwater percolated. Greater penetration of water is expected in recently disturbed soils whose original bulk density relationships have been changed.

In Fig. 31, the available records of soil-water tritium concentrations at the 11A station are summarized for the 1966-1967 period. At the 11A station, on the south rim of the Sedan crater, soil-water tritium concentrations had become stable again by August 1966 after the large flux of rain received in the previous winter. It is possible that some effects were still taking place at the 4- and 5-ft depths in the summer of 1966. The winter rains of 1966-1967 reduced tritium concentrations by February 1967 after almost 2 in. of rain in December 1966 and January 1967. March rain of over 0.6 in. did not affect the 11A station, while at 16A (Fig. 30) reductions were seen at 6 in. Almost
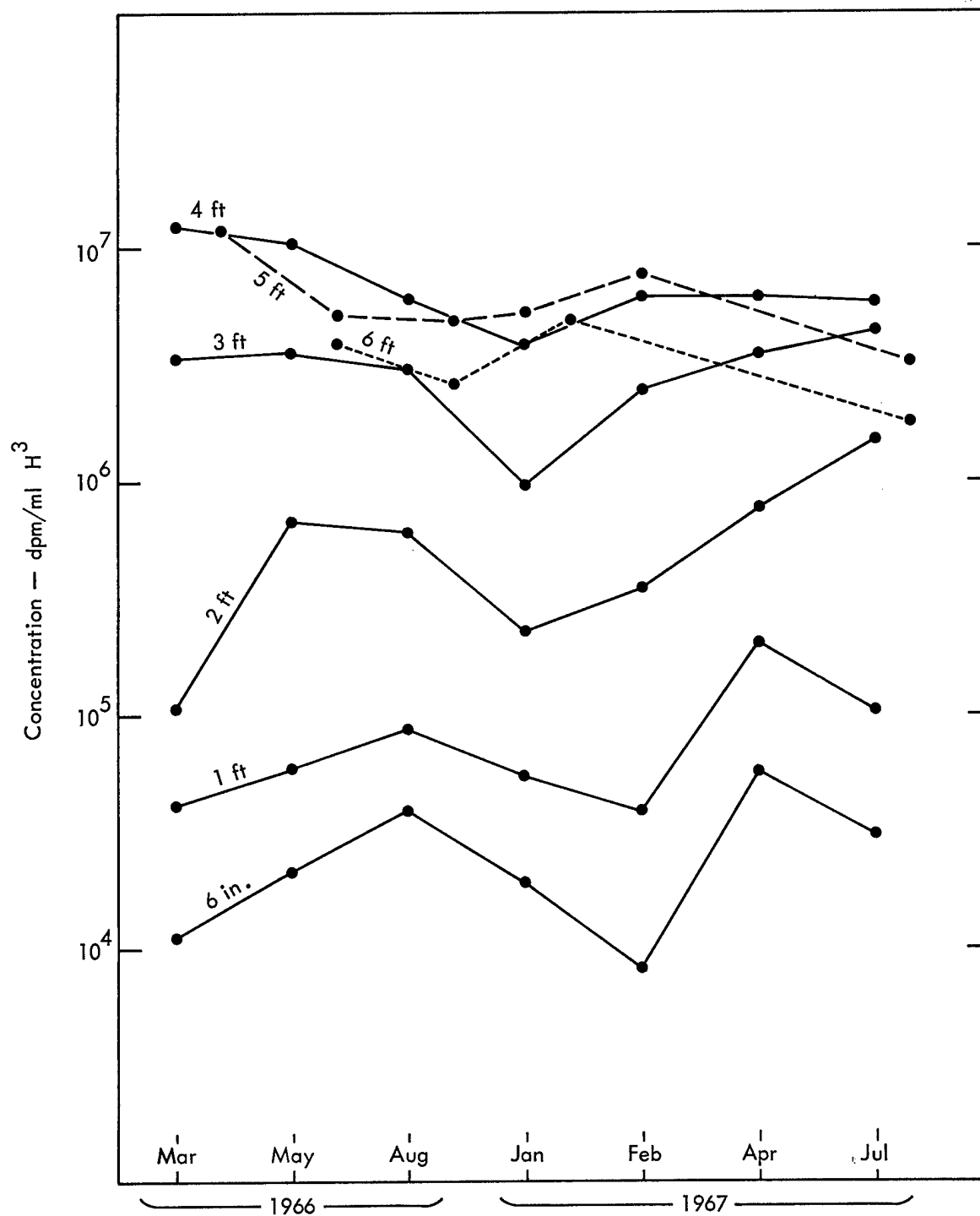
-36-

Fig. 31. Soil-water tritium concentrations for samples from 11A station
on crater lip (March 1966 to July 1967).

0.7 in. of rain in July 1967, however, reduced tritium concentrations at the 6-in. and 1-ft depths at the 11A station.

The salient feature of these records of tritium concentrations, made possible by periodic sampling, is the ability of the

ejecta-soil water (THO) system to re-
plenish tritium concentrations in the
active zone of soil-water volume changes,
as the disintegrations per minute per
gram data indicate. The obvious source
of the tritium brought into the surface
active zone is in the deeper strata (below
3 ft) which normally do not enter promi-
nently into soil-water dynamics in this
area, according to the available data. In
Fig. 31, a loss is seen in the 4-ft concen-
trations at the end of the period of these
records, and a similar reduction at 4 ft
is seen at 16A on Fig. 30. A more subtle
loss is evident at 20A in Fig. 27, but the
20A station may be affected by micro-
topographic considerations. This station
is on a slope, and part of the effective
soil-water movement may be lost in a
lateral drainage component. Losses are
also seen at 5 ft on 11A (Fig. 31) where
deep samples were obtained frequently
during this period.

SUMMARY OF SOIL STUDIES

The significant information to be ob-
tained from the soil water tritium sum-
maries given in Figs. 27, 30, and 31 is
as follows:

1. At any given time postshot, tritium
concentrations in soil water extracted
from nuclear crater ejecta are the
product of the original depositional
level and the specific ecological
factors operating at the site. These
factors include seasonal rainfall
amount and distribution, microcli-
matic and microtopographic features
of the site, and the biological sys-
tems associated with the tritiated
substratum. Soil-water movements
which are determined by ecological
and climatological factors produce
the variations observed in tritium
concentrations in the active zone of
the soil profile.

2. The replenishment of tritium in the
active zone of the Sedan crater
ejecta soils is due to the specific
soil-water regime of the desert
region in which the crater occurs.
In another region, an endemic set
of environmental factors would pro-
duce a different pattern of soil-
water movements.

3. Net losses of tritium as THO from
the Sedan ecosystem may be esti-
mated if adequate data are available
for a period which covers several
typical annual cycles. Because
vertical soil-water and vapor move-
ments cause variations in tritium
concentrations in the soil profile
during the period of water gain and
loss, data should be expressed in
terms of specific activity to allow
comparison of concentrations from
any time of the year.

The behavior of residual tritium from
a nuclear detonation in other biotic regions
would be affected most strongly by climatic

factors, such as rainfall amounts and distribution and edaphic factors, namely the physical and chemical characteristics of the soil type or, more appropriately, the parent materials. Since most ejecta is composed of geological materials from below the shallow surficial zone in which soil formation takes place, the physical and chemical characteristics of unweathered regolith will compose the physical system in which residual tritium will be injected. These parent material characteristics may differ significantly from highly weathered, bioclimatically produced soil types that are found in some parts of the world.

Soil-water dynamics may be considerably different from those which occur at Sedan crater when the soil type contains greater amounts of clay-size particles. The effects of the clay fraction of soils upon the permeability and percolation rate of water in soils are well known. The water of hydration associated with clay particles may act as another compartment in which soil-water tritium may be involved. Although the magnitude of this compartment may not be large, an opportunity for isotope mass effects may be present in crystalline lattice systems where tritium occupies structural positions subject to exchange. Research by Stewart[10] indicates that the level of exchange of tritium into this colloidal water compartment is not very great under laboratory conditions, even after periods of long exchange.

SEDAN EJECTA TRITIUM INVENTORY

The soil-water tritium data discussed in this report have provided detailed information on the current distribution of residual tritium as THO in the Sedan post-shot environment. We might attempt to utilize these data to obtain some concise expression of the total effects that have occurred in the macrosystem being studied at Sedan crater since the detonation on 6 July 1962. To this end, a study has been made of the current inventory of tritium in the Sedan ejecta with the data and by the methods used in this research. The limits of the method of extracting tritium from soil materials by lyophilization are fully recognized by the investigators, and, utilizing certain data presently available, it has been possible to relate total tritium per gram of soil to the concentrations per milliliter or gram found in this report. It is more realistic to consider the tritium obtained by our methods as biologically available tritium, although it is realized that the more tightly held soil water and tritium may exchange rapidly with the class of soil water obtained by lyophilization.

By converting all soil-water tritium concentrations to disintegrations per minute per gram of soil, and for each station, integrating the tritium depth profile to the 6-ft depth, a value representing tritium concentrations as $\mu Ci/ft^2$ was obtained. By performing a double integration

of distance and azimuth relationships with tritium concentrations, an approximation of the total biologically available tritium from the crater lip to an effective distance of 3000 ft from GZ was obtained. The calculational procedures and the assumptions made in this inventory study will be described in a future report.

The value obtained is 6.2×10^4 Ci of tritium which represents the inventory of biologically available tritium in the ejecta field. Since we have determined that free water obtained by lyophilization represents 70% of the total free and exchangeable tritium, the total inventory is therefore 8.9×10^4 Ci, which is equivalent to 1.2×10^5 Ci at shot time (T_0). The total amount of tritium in the ejecta field at T_0 was estimated at 1.6×10^6 Ci $\pm$ 50%.

The tritium inventory in the Sedan ejecta five years after the detonation, based on measurements of free and exchangeable tritium in soil samples collected in June and July 1967, is therefore 5 to 6% of the estimated inventory of residual tritium in the ejecta at shot time. When more data are available it will be possible to derive a half-residence time for residual tritium in the Sedan ecosystem.

ACKNOWLEDGMENTS

REFERENCES

1. J. J. Koranda, Residual Tritium at Sedan Crater, Lawrence Radiation Laboratory, Livermore, Rept. UCRL-70292, (1967).

2. F. T. Hatch, J. L. Moore, and J. J. Koranda, Enhanced Primer-Template Function of Liver DNA from Kangaroo Rats Living in a Tritiated Environment, Lawrence Radiation Laboratory, Livermore, Rept. UCRL-70318, Abstract (1967).

3. D. C. Lewis and R. H. Burgy, "The Relationship between Oak Tree Roots and Groundwater in Fractured Rock as Determined by Tritium Tracing," J. Geophys. Res. 69 (12), 2579-2588, 1964.

4. W. D. Richards, Geologic Study of the Sedan Nuclear Crater, Lawrence Radiation Laboratory, Livermore, Rept. PNE-240F (1964).

5. R. H. Carlson and W. A. Roberts, Project Sedan: Mass Distribution and Throwout Studies, The Boeing Company, Seattle, PNE-217F (1963).

6. J. B. Knox, Water Quality in Flooded Craters Produced by Nuclear Explosives, Lawrence Radiation Laboratory, Livermore, Rept. UCID-4741 (1964).

7. U. Zimmerman, K. O. Münnich, and W. Roether, "Downward Movement of Soil Moisture Traced by Means of Hydrogen Isotopes," in Isotope Techniques in the Hydrologic Cycle, Geophysical Monograph Series No. 11 (American Geophysical Union, National Academy of Science, National Research Council, Washington, D.C., 1967).

8. M. D. Nordyke and M. M. Williamson, The Sedan Event, Lawrence Radiation Laboratory and U.S. Army Corps of Engineers, Livermore, Rept. PNE-242F (1965).

9. W. H. Rickard and J. R. Murdock, "Soil Moisture and Temperature Survey of a Desert Vegetation Mosaic," Ecology 44(4), 821-824, 1963.

10. Gordon L. Stewart, "Fractionation of Tritium and Deuterium in Soil Water," in Isotope Techniques in the Hydrologic Cycle, Geophysical Monograph Series No. 11 (American Geophysical Union, National Academy of Science, National Research Council, Washington, D.C., 1967).

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